1959 CONVENTION—LOS ANGELES—FEBRUARY 23-26, 1959

FEBRUARY 1959
No. 8
VOL. 30

JOURNAL
OF THE
AMERICAN CONCRETE INSTITUTE

Papers and Reports.....829-924

55-53 **Prestressed Pavement—A World View of Its Status**.....
SUBCOMMITTEE VI, ACI COMMITTEE 325 829

55-54 **Tremie Concrete Controlled With Admixtures**...
J. WAYMAN WILLIAMS, JR. 839

55-55 **Effects of Longitudinal Forces in Portal Frame Supporting a Highway Bridge Deck**.....
TUNG AU and THOMAS D. Y. FOK 851

55-56 **Expansion and Cracking Studied in Relation to Aggregate and the Magnesia and Alkali Content of Cement**.....W. C. HANSEN 867

55-57 **Wear-Resistant Concrete Construction**.....
SHU-T'IEN LI 879

55-58 **Specific Surface of Aggregates Applied to Mix Proportioning**.....B. G. SINGH 893

Concrete Briefs.....903-908

Current Reviews.....909-924

News Letter..... 1-32

ACI
PROCEEDINGS
VOL. 55

Detailing Practices

Buildings to Bridges

58 Illustrative Drawings

The ***Manual of Standard Practice for Detailing Reinforced Concrete Structures (ACI 315-57)*** incorporates under one cover the previous separate editions on detailing of buildings and highway structures. It is a correlation of the latest improved methods and standards for preparing drawings for the fabrication and placing of reinforcing steel. Sections on detailing and fabricating shop practice are translated into practical examples in typical drawings. Spiral bound to lie flat, it is the only publication of its kind in English and is meeting wide acclaim among designers, draftsmen, and engineering schools.

Full Price $4.00 **ACI Members** $2.50

AMERICAN CONCRETE INSTITUTE

PUBLICATIONS

P.O. Box 4754, Redford Station Detroit 19, Mich.

FEBRUARY 1959

No. 8

Vol. 30

PROCEEDINGS VOL. 55

JOURNAL
OF THE
AMERICAN CONCRETE INSTITUTE

Published by the American Concrete Institute under the authority of its Board of Direction

President

DOUGLAS McHENRY

Vice-Presidents

PHIL M. FERGUSON

JOE W. KELLY

Directors

ARSHAM AMIRIKIAN

WILLIAM H. ARMSTRONG

S. J. CHAMBERLIN

CLAYTON L. DAVIS

BRUCE E. FOSTER

ROBERT C. JOHNSON

BRYANT MATHER

RAYMOND C. REESE

LEWIS H. TUTHILL

C. D. WAILES, JR.

STANTON WALKER

CEDRIC WILLSON

Past Presidents

CHARLES S. WHITNEY

FRANK KEREKES

WALTER H. PRICE

Secretary-Treasurer

WILLIAM A. MAPLES

Managing Editor

ROBERT E. WILDE

Advertising Manager

CHARLES L. COUSINS

Manager, Publication Sales

ISABELLE DAVIS

Membership Secretary

EVELYN SCHLITZ

Cost per copy $1.50. Extra copies to ACI members $1.00.

Papers, committee reports, and other contributions to the **Proceedings** pages of this Journal, as submitted in furtherance of Institute objectives, are, if published, accepted on the sole responsibility of their authors. Institute authority attaches only to standards adopted as provided in the Bylaws.

Advertising. See statement under "Alphabetical List of Advertisers," final page **News Letter section.**

Membership dues and Journal subscription rates. Members receive the Journal as one of the considerations of dues payment. Membership grades are: Individual (U. S., its possessions, and North and Central America), $15, Individual (all other foreign countries), $12, Corporation, $50, Contributing, $100, Junior, $7.50, Student, $5. Subscription price is $18 per year, payable in advance. The Journal is issued monthly, July to June (the volume year being completed by title page, contents, indexes, and closing discussion in Part 2 of the subsequent September and December issues).

Bound volumes 1 to 53 of PROCEEDINGS of the AMERICAN CONCRETE INSTITUTE (1905 to 1957) are for sale as far as available at prices to be had on inquiry of the Secretary-Treasurer. Special prices apply for members ordering bound volumes in addition to the monthly Journal.

Address: American Concrete Institute, P.O. Box 4754, Redford Station, Detroit 19, Mich. **Copyright©, 1959,** American Concrete Institute. Printed in U. S. A. Entered in the Post Office at Detroit, Mich., as mail of the second class under provisions of the Act of Mar. 3, 1879.

the ACI JOURNAL

is edited by the Secretary of the Technical Activities Committee under the direction of the Committee

WALTER J. McCOY
Chairman

DOUGLAS McHENRY
(ex officio)

WILLIAM A. MAPLES
Secretary

G. E. BURNETT

E. A. FINNEY

CLYDE E. KESLER

BRYANT MATHER

MICHAEL V. PREGNOFF

L. H. TUTHILL

WILLIAM A. MAPLES
Editor

ROBERT E. WILDE
Managing Editor

ROBERT G. WIEDYKE
Associate Editor

RICHARD A. MEHOKE
Assistant Editor

MARIAN PATTEN
Editorial Assistant

RUTH GABLE
Editorial Secretary

Coming next month in the JOURNAL

JOURNAL line-up for March includes the following:

"Commentary on Concrete" by Robert F. Legget, originally presented at the official dedication ceremonies of the new headquarters building of the Institute.

•

Coauthors Warren A. Shaw and J. R. Allgood present their research paper on "Blast Resistance of Reinforced Concrete Beams Influenced by Grade of Steel."

•

"Control of Concrete Mixes" prepared by Edward A. Abdun-Nur and Joseph J. Waddell presents control procedures and data developed to attain uniformity and quality control under a variety of conditions.

•

A. M. Neville reviews in some detail the "Role of Cement in the Creep of Mortar."

•

"Design and Construction of a Modern Parking Garage" by Walter E. Riley presents a construction story of a six-level parking garage recently built in Phoenix Ariz.

•

Discussion of papers published in the July, August, and September, 1958, issues will appear in the March JOURNAL, in accordance with the Institute's quarterly publication schedule for *Proceedings* discussion.

Manuscripts of papers, discussions, and reports should be sent in triplicate to:

Secretary, Technical Activities Committee
AMERICAN CONCRETE INSTITUTE
P. O. BOX 4754, REDFORD STATION, DETROIT 19, MICHIGAN

Title No. 55-53 reports on experiment and achievement in prestressed pavements throughout the world. Six factors selected for discussion include: design practices; choice of prestressing methods; types of aggregates and cements; methods of reducing subgrade friction; load tests and performance records; cost comparison with conventional pavement.

Prestressed Pavement

a world view of its status

Reported by Subcommittee VI, ACI Committee 325*

SUBCOMMITTEE VI OF ACI COMMITTEE 325 was assigned the task of preparing a report on the status of prestressed concrete pavement throughout the world. It was not intended that the subcommittee should pass judgment on the work already accomplished nor was it intended that the report should include firm recommendations for work to be undertaken in this country. It was merely intended that various factors related to prestressed pavement be briefly discussed so that the subcommittee might be able to recommend where emphasis should be placed or where attention might first be focused in future studies. In other words, it was anticipated that the report might reveal a preliminary definition of the subcommittee's future work and it was hoped that by presentation of the report interest in prestressed pavement might be stimulated.

Sources of information for the material in this report are letter contacts with those agencies abroad which have conducted the work, technical and semitechnical papers and articles describing the foreign work, the close association of subcommittee members with the investigations undertaken in the United States, and papers describing the local work. A partial list of the literature reviewed is included at the end of the text.

The largest share of investigative work in the form of field slabs and tests has been undertaken in England and France, and a review of the design procedures employed in these countries was presented at the 36th annual meeting of the Highway Research Board in 1957.[1] There are reports of work done in Australia, Germany, India, Belgium, and Russia but in most cases there

*Prepared as a part of the work of ACI Committee 325, Structural Design of Concrete Pavements for Highways and Airports, and presented at the ACI 54th annual convention, Chicago, Ill., Feb. 26, 1958. The report was submitted to letter ballot of the main committee which consists of 16 members; 13 members returned their ballots, all voting affirmatively.

are not sufficient technical details immediately available to permit study and analysis of these works. Efforts will be made to obtain these details, however, and all the problems involved and their solutions will be studied before a guide to prestressed pavement design and construction is prepared.

In assembling information for this presentation the six factors selected for discussion were:

1. Design practices
2. Choice of prestressing methods
3. Types of aggregates and cements
4. Methods of reducing subgrade friction
5. Load tests and performance records
6. Unit costs

There are, of course, many other items of interest which could be included but it is believed that in this preliminary discussion these represent the principal factors with which the committee is concerned.

DESIGN PRACTICES

Prestressing functions in pavement slabs to augment the strength of concrete in tension by the application of an initial compressive stress before the slabs are subjected to loads. To induce this initial stress two systems of design and construction have been employed. One is the "continuous" type of slab wherein no prestressing steel is used and the stressing is effected by using hydraulic jacks between abutments and the slabs to be stressed, or between the slabs themselves. Slabs of this type are continuous in that there are no expansion joints, and the use of jacks results in gaps that are subsequently filled. The other system is the "individual" type of slab in which stressing is accomplished through the use of high tensile strength cables which are post-tensioned or stretched after the concrete is hardened.

Cables or prestressing wires have been used in a variety of patterns, the most common being longitudinal and transverse. In a number of instances,[2] however, wires have been placed at angles to the center line (e.g., 18½ deg, 30 deg, 45 deg).

Most experimental slabs have been rectangular, but on some jobs triangular slabs have been employed and on the London Airport rollers were inserted between these triangular slabs.

Design methods to date have been somewhat empirical. Enough prestress is applied longitudinally to prevent transverse contraction cracks. Contracting slabs generally are subject to simultaneous temperature warping restraint stress involving compression in the bottom fiber, assisting the prestress in decreasing tension stresses due to load and contraction. Expanding slabs are subject to the greatest combined flexural bottom fiber tension from load and daytime warping restraint, which is counteracted by the prestress as well

Subcommittee VI of ACI Committee 325, Structural Design of Concrete Pavements for Highways and Airports, was assigned the task of preparing a report on the status of prestressed concrete pavement throughout the world. JOHN A. BISHOP, U. S. Naval Civil Engineering Laboratory, Port Hueneme, Calif., is the subcommittee chairman. Members of the committee are BENGT F. FRIBERG, Consulting Engineer, St. Louis, Mo.; ROBERT HORONJEFF, Institute of Transportation and Traffic Engineering, University of California, Berkeley; JOSEPH H. MOORE, Pennsylvania State University, State College; L. A. PALMER, Bureau of Yards and Docks, Department of the Navy, Washington, D. C.; and THOMAS B. PRINGLE, Office, Chief of Engineers, Department of the Army, Washington, D. C.

as by frictional restraint stress under the expanding slabs.[15] The prestress design value accordingly is not limited to the amount of residual prestress near midlength of contracting slabs, variously recommended at 100 to 300 psi. Investigators differ in their opinions on the magnitude of residual prestress necessary, but the range given represents a consensus of the authors of reports reviewed.

Slab thicknesses have been *selected* rather than *designed*, generally with estimated necessary cable cover as the determining factor.

The amount of longitudinal prestressing applied when longitudinal cables only or combinations of longitudinal and transverse cables have been employed on highway slabs has varied from 90 to 410 psi with an average of 225 psi. On airfield slabs with these same cable arrangements the average has amounted to about 450 psi. Where diagonal cables were used to effect the longitudinal prestress the average was about 275 psi.

There have been several instances where gap jacks were used and in these cases an average of 575 psi of longitudinal prestress has been applied, considerably higher it will be noted than when cables were used.

Transverse prestressing, as such, has not been universally employed. It was induced as a component of diagonal prestressing when those patterns were used and was the only stressing employed on those works where triangular shaped slabs were constructed. It does not appear to be necessary except where slab widths exceed about 12 ft.

English practices

Prestressed pavement slabs in England have, for the most part, been of the individual type—that is, using cables with expansion joints separating the slabs. The relative merits of the individual and the continuous types of slabs have been argued at length in England and proponents of the former appear to have advanced the more overweighing advantages. The principal one of these is the fact that the amount of prestress, except for the effects of subgrade friction, will remain nearly constant in pavements in which expansion is permitted by the joints. Since the continuous slabs, formed using

jacks, require abutments to resist end thrust, and the jack gaps are filled, the slabs cannot expand freely and so the stresses vary with moisture and temperature changes with the result that it is difficult to predict the amount of initial stressing necessary to produce the desired residual.

English engineers have used slabs of 6 in. constant thickness extensively but the triangular slabs at the London Airport were 6½ in. thick. The largest section of prestressed pavement constructed there had a 10 in. thick constant section and on one slab where gap jacks were used the thickness was 4 in.

Longitudinal prestressing in England has conformed to the average figures mentioned above and transverse prestressing was limited to less than 50 psi except in the triangular slabs.

Experience in France

In France both individual and continuous type slabs have been constructed. In 1947 the 1365-ft section at Orly Aerodrome consisted of triangular slabs with transverse cables and abutments; on the 1953 project at the same site gap jacks were used along with transverse cables on continuous rectangular slabs. Other works[10] such as those at Luzancy and at Esbly involved the use of diagonal cables while the 984-ft section at Bourg-Servas was continuous with gap jacks and abutments.

One experimental pavement was a slab with the edges thinner than the center but the rest were of a uniform section averaging about 6 in. thick. Longitudinal prestressing applied to slabs in France has been of the same order of magnitude as in other countries except on the Bourg-Servas Road where a total of 740 psi initial prestress was induced, this in a continuous slab with abutments and gap jacks. French engineers are not in agreement on the need for transverse prestressing.

Germany and other countries

Some of the early analytical work on prestressed slabs in Germany,[6,7] antedates that undertaken in other countries but the application of their theories has been for the most part in connection with slabs supported as bridge floors, roofs, etc., and not with pavement slabs. German engineers have designed and constructed at least two experimental pavement sections and their design practices have been much the same as in other countries

In Belgium, Algiers, and Australia prestressed pavements have been constructed using essentially the same practices as have been employed in other countries. In Australia, however, a 2¼ in. thick section has been constructed in the center of an already existing concrete runway. No details of the prestressing techniques on this overlay type pavement are presently available.

United States

As implied previously only a few prestressed pavements have been constructed in the United States. The largest project to date was the well known effort of the Bureau of Yards and Docks at the Patuxent River Naval Air

Station in 1953-54.[11] This was a 500 ft long, 12 ft wide, and 7 in. thick slab prestressed with longitudinal cables to approximately 700 psi initially. The design techniques and details of this pavement may be found in Reference 11.

In 1955 the U. S. Army Corps of Engineers constructed an experimental pavement at their test area in Sharonville, Ohio. This was a 4 in. thick overlay type section with the initial compressive stress induced by the *pretensioning* of cables longitudinally and transversely to perimeter abutments.

In 1956, as part of a cooperative research project between the U. S. Bureau of Public Roads, the Missouri State Highway Commission, and the University of Missouri, 16 field slabs 25 in. wide and 222 in. long were built, including 5½ and 8-in. depths, dense and air-entrained concrete, and uniformly distributed prestress of 0, 100, 300, and 500 psi. The prestress is maintained constant by spring assemblies and the project is intended for continuing observations of creep and warping under field conditions for different prestress levels. As far as is known, nothing to date has been published on this experimental work.

The only other significant field effort in the United States has been the Jones and Laughlin Steel Co. experimental highway pavement project in Pittsburgh undertaken during 1956 and 1957. This was a 400 ft long, 12 ft wide, and 5 in. thick pavement prestressed longitudinally in such a manner as to produce approximately 450 psi at the slab ends. A complete description of this project was presented at the 37th annual meeting of the Highway Research Board.[12]

CHOICE OF METHODS OF PRESTRESSING

There are two general methods of inducing the necessary initial compressive stress in the concrete of pavement slabs: post-tensioned steel cables; and jacks reacting against abutments of some description. Basically these are techniques used to accomplish the same result and the end products, as Harris points out,[4] should be referred to as "mobile" or "immobile" depending on the degree of freedom from subgrade restraint. There are, of course, advantages and disadvantages inherent in both systems and there are many factors involved when weighing one against the other.

In slabs of the individual type, with expansion joints between slabs, the stress changes due to variations of weather and moisture will not be great unless the distance between joints is excessive. Analytical and experimental studies show that when expansion joint spacing exceeds about 400 ft the stress changes become substantial and the pavement tends to become continuous. This length is an average figure and, as mentioned, is dictated by the restraint to slab movement occasioned by the physical characteristics of the subgrade.

One factor important to consider in selecting a method or technique (in prototype pavement but not necessarily in experimental work) is the comparative difficulty involved in making necessary repairs to the pavement and

to utilities which must cross under the prestressed areas. The pavement stressed by jacks may have the advantage on this point.

The problems involved in prestressing pavement on vertical and horizontal curves have been much discussed by investigators. It is apparent that attempts to prestress anything except short sections of curves by either method would be a difficult task.

Probably the largest single factor discussed by investigators in advancing the relative merits of the two general methods of prestressing pavements, apart from the technical considerations, is engineering economics. The cost of abutments versus steel for cables, jacks versus joints, and other cost comparisons have been issues which sometimes appear to govern the choice of methods or techniques.

AGGREGATES AND CEMENTS

Few of the publications describing prestressed pavement work do more than briefly mention the aggregates, cements, and resulting concretes used. It follows, however, from the comments of most authors that the necessity of using high quality concretes composed of sound, dense aggregates (with ordinary or high-early-strength cements) cannot be overemphasized. It is also apparent that water-cement ratios should be kept to a minimum to avoid the possibility of undue loss of prestress due to creep. Compressive strengths at 28 days ranging from 3000 to over 8000 psi have been reported, and moduli of rupture of 300 to over 750 psi have been used.

In some instances high-alumina cement has been used but the only advantage cited lies in the high rate of concrete placing possible.

The records examined fail to indicate the use of accelerators or workability agents apart from some early investigative work in laboratories.

METHODS OF REDUCING SUBGRADE FRICTION

It is important to reduce friction between the pavement slab and the subgrade to a minimum since the restraint to movement of the slab is the major contributing factor in prestress loss, and governs the length which can be used. Much work has been done and is underway on techniques of reducing restraint, and coefficients of friction as low as 0.5 have been obtained in laboratories. On practically every field venture, however, tests have been conducted to determine a coefficient and to define the method to be used for reducing friction on that particular job. These tests generally have taken the form of pull tests on small slabs resting on sand, paper, stone chips, etc., carefully placed. In almost all cases the coefficients thus determined have been appreciably lower than measured in the field slab. This is as expected because on the large jobs laboratory controlled conditions are usually not possible.

Various techniques have been employed, with a sand layer or a sand layer covered with waterproof paper being the most commonly tried. Efforts have

been made, however, to use bituminous materials for a sliding layer, but as yet these have not been too successful. A refinement of interest was an attempt to use a thin layer of one particle size sand, with spherical shaped grains acting much like ball bearings. An extensive investigation on possible friction reducing techniques is underway in England's Road Research Laboratory and it is quite probable that similar studies are in progress in research establishments in this country.

LOAD TESTS AND PERFORMANCE RECORDS

The proof of success of any pavement is, of course, the manner in which it sustains the loads imposed and its long term performance. It is apparent from the published reports on prestressed pavement that in all cases the load carrying capacity of this type of pavement has greatly exceeded that of conventional pavement of similar thickness. The records of those pavements which have been in actual service for some time also indicate that performance from the standpoint of maintenance and repairs needed compares favorably with conventional pavement. Load tests, as such, have been conducted for the most part on slabs in or simulating airfield pavements, with some notable exceptions such as the Jones and Laughlin highway slab.

Extensive load tests were made on a test slab at the Orly Aerodrome in 1946 and excellent load-deflection data have been published.[8] Loads in excess of 140 tons were sustained with minor residual deflection on a subgrade with $k = 55$ psi per in. This represents a load carrying capacity nearly ten times that which could be expected on this subgrade with a conventional pavement. Repetitive load tests were made on this pavement also and none of the loadings resulted in distress in the form of permanent cracks.

Load tests were also made on the experimental section of the London Airport and on the full scale work at Maison-Blanche with essentially the same comparisons with conventional pavement being possible.

The U. S. Navy's load tests on the 7-in. pavement at the Patuxent River Naval Air Station were sufficiently extensive to confirm what may be expected of a prestressed slab as far as load carrying capacity is concerned. Plate sizes in these tests ranged from 2 to 20 in. in diameter and loads were imposed on the interior of the slab, at the edges, and at the locations of some shrinkage cracks which developed.

As pointed out by Cholnoky[11] no moment failures occurred under loads of 200,000 lb and there were indications that loads up to 350,000 lb could be sustained without distress. It was concluded from these tests that the prestressed slab had a capacity well beyond what a conventional pavement would have on the same subgrade and that deflections normally considered excessive may be experienced without distress in the pavement structure.

The details of the load tests conducted on the Jones and Laughlin experimental highway slabs are described in Reference 12; the results indicate that

this 5 in. thick slab was apparently satisfactory for edge loadings up to 40,000 lb. In other words, there was a tremendously increased load carrying capacity induced by prestressing. The description[12] of this test section contains many details of the instrumentation, quantities measured, and testing procedures which would be of interest to anyone concerned with prestressed pavement.

The 4 in. thick overlay type pavement of the Corps of Engineers was stressed to failure by using dual wheel loads up to 100,000 lb, and the first sign of failure did not occur until after some 3000 passes of this load.

UNIT COSTS

While a number of analyses have been made comparing the cost of prestressed pavement with conventional pavement, it is not possible, at this time, to present significant figures. This is, of course, due to the fact that a large share of the work accomplished to date has been experimental and so the costs are naturally higher for prestressed pavement than might be expected or hoped for. It is apparent, however, that costs will be reduced when certain techniques are perfected to the point where they are more or less commonplace, and when a sufficient number of contractors are experienced enough to create competition. Reports from abroad indicate that in some countries conventional and prestressed pavement differ little in cost of construction, and while it is too early to define maintenance costs over a long period, it is becoming apparent that the prestressed pavement may be more economical to maintain. This, however, cannot be definitely established until more service records are available.

Studies, such as those made by Jones and Laughlin, which include recommendations for possible cost reductions are extremely valuable in effecting a competitive situation in this country between prestressed pavement and what is now considered conventional.

The U. S. Navy's Bureau of Yards and Docks has had engineering studies made in connection with some of their proposed work in which the feasibility of using prestressing has been seriously analyzed and considered. In some cases, the cost differential is slight and it is probable that some prestressed pavement will be used in their airfield construction in the near future.

SUMMARY

After reviewing articles originating in many parts of the world over a 15 year period, there are several points which may be listed as indicative of the present status of prestressed concrete pavement:

1. It is possible to augment sufficiently the strength of concrete in tension by inducing an initial compressive stress that a pavement slab so constructed will have a load bearing capacity many times that of a conventional concrete slab of the same thickness on the same subgrade.

2. The two general methods or techniques by which the concrete may be so strengthened are, namely, through the use of post-tensioned cables or through

the use of hydraulic jacks reacting against abutments. A number of pavement slabs have been constructed with each technique.

3. A number of arrangements of cables have been used, the most common being longitudinal and transverse, but diagonally placed cables have been used in a number of instances as have combinations of cables and jacks.

4. Slabs of both rectangular and triangular shape have been constructed.

5. Thicknesses appear to have been selected with the cable cover considered necessary as the determining factor. In most cases constant thickness sections have been used.

6. Slabs may be "mobile" or "immobile" depending on whether or not they may freely expand. In the former, the prestress remains more or less constant while in the latter, the prestress losses may be substantial because of changes in length due to temperature and moisture variations. In either type it is necessary only to induce sufficient initial compressive stress that regardless of what happens there will be a residual prestress of 200-300 psi—this being an average figure varying with the loads the pavement will be expected to sustain.

7. Restraint to movement of the slab is a function of the friction between subgrade and slab. Friction must be reduced to a minimum if undue losses are to be avoided, a coefficient of 0.5 being suggested as a maximum. This value has been approached using sand or sand and paper as the friction reducing layer. This restraint to movement is the major factor in limiting the length of prestressed slabs and more study on feasible methods of reducing friction is needed.

8. High quality concretes composed of sound, dense aggregates with ordinary or high-early-strength cement should be used. Water-cement ratios should be kept to a minimum to reduce prestress loss due to creep.

9. Prestressed pavement is not yet competitive from a cost standpoint with conventional pavement, but it is becoming so. The cost differential will be reduced as contractors gain experience and techniques are perfected.

10. Few prestressed pavements have been constructed in this country but programs under which this type of construction have been undertaken have been exceptionally well conceived, carried out, and reported. There is little doubt that the experiences of those agencies which have had the programs will stimulate and benefit other investigators in their search for answers to the remaining unsolved problems.

REFERENCES

Reports, papers, and articles reviewed in preparation of this preliminary status report are listed below. Many contain bibliographies which include further valuable references on the subject. Not all the publications are specifically cited in the text.

1. Melville, Phillip L., "Review of French and British Procedures in the Design of Prestressed Pavement," *Bulletin* 179, Highway Research Board, May 1958, pp. 1-12.

2. Thomas, F. G., *et al.* (Prestressed Concrete Development Committee), "Developments

in Prestressed Concrete," *Proceedings*, Institution of Civil Engineers (London), V. 8, Session 1957-58, Nov. 1957, pp. 293-322.

3. Stott, James Pearson, "Prestressed Concrete Roads," (with discussion), *Proceedings*, Institution of Civil Engineers (London), Part II, V. 4, No. 3, Oct. 1955, pp 491-538.

4. Harris, Allan James, "Prestressed Concrete Runways: History, Practice and Theory," *Airports and Air Transportation*, Nov.-Dec. 1956, pp. 109-111.

5. Nagarajan, R., "Prestressed Concrete Pavements," *Indian Concrete Journal* (Bombay), June 15, 1955, pp. 216-221.

6. Kirchner, Georg, "Stress Distribution in Transversely Prestressed Slabs," *Beton- und Stahlbetonbau* (Berlin), No. 2, 1955 (in German).

7. Franz, Gotthard, "Fundamentals of Prestressed Slabs," *Beton- und Stahlbetonbau* (Berlin), No. 4, No. 5, No. 6, 1953 (in German).

8. Netter M., "The Prestressed Concrete Runway at Orly," *Annales de l'Institut Technique du Bâtiment et des Travaux Publics* (Paris), No. 5, Jan. 1948 (in French).

9. "Research on Prestressed Road," *Concrete and Constructional Engineering* (London), V. 48, No. 12, Dec. 1953, pp. 399-402.

10. Dollet, H., and Robin, M., "The Experimental Prestressed Concrete Road at Bourg-Servas," *Travaux* (Paris), Jan. 1954 (in French).

11. Cholnoky, Thomas, "Prestressed Concrete Pavement for Airfields," ACI JOURNAL, V. 28, No. 1, July 1956 (*Proceedings* V. 53), pp. 59-84.

12. Morcell, Ben, Murray, John J., and Heinzerling, John E., "Experimental Prestressed Concrete Highway Project in Pittsburgh, Pennsylvania," *Proceedings*, Highway Research Board, V. 37, 1958, pp. 150-193.

13. Coppage, Edwin J., "Suggested Design for an Experimental Prestressed Concrete Pavement," *Roads and Streets*, Aug. 1957.

14. "German Recommendations for Prestressed Concrete," *Concrete and Constructional Engineering* (London), V. 49, No. 6, June 1954, pp. 189-192.

15. Friberg, Bengt F., "Pavement Research, Design, and Prestressed Concrete," *Proceedings*, Highway Research Board, V. 34, 1955, pp. 65-84.

Title No. 55-53 is a part of copyrighted Journal of the American Concrete Institute, V. 30, No. 8, Feb. 1959 (Proceedings V. 55). Separate prints are available at 50 cents each.

American Concrete Institute, P. O. Box 4754, Redford Station, Detroit 19, Mich.

Discussion of this paper should reach ACI headquarters in triplicate by May 1, 1959, for publication in the Part 2, September 1959 JOURNAL.

Title No. 55-54, noting that nonuniform quality and excessive laitance are disadvantages usually associated with tremie concrete, reports on laboratory tests and field applications which show that retardation and air entrainment will reduce laitance and improve the flow, the uniformity, and the pattern of heat development in tremie concrete.

TREMIE CONCRETE Controlled With Admixtures

By J. WAYMAN WILLIAMS, JR.

TREMIE CONCRETE IS A TERM used to designate concrete placed underwater by gravity feed through a vertical pipe. Tremie concrete has been used largely for sealing cofferdams and caissons, for building subaqueous foundations, and for holding precast tunnel sections or other objects in place under water.[1]

Tremie placement is not new. A British engineer, Walter R. Kinipple, conducted experiments with concrete under water as early as 1856.[2] A French engineer, H. Heude, reported using a timber shaft 16 in. square to place concrete underwater for a railroad bridge foundation in 1885.[3] A forerunner of our modern tremie equipment was sketched in *Engineering News* in 1894. This 8-in. tremie pipe was 10 ft long with a 3-ft hopper at the top. The contractor, W. H. Ward, reported successful use on jobs in Lowell, Boston, and Brooklyn.[4] Large tremie projects from early years include the Detroit River Tunnel in 1906 and a Pearl Harbor drydock in 1909-1913.[5]

Using the tremie method for reinforced structural concrete is a rather recent development. In 1940, the piers for the Potomac River Bridge were con-

J. Wayman Williams, Jr. (ACI member) is manager of technical service for Sika Chemical Corp., Passaic, N. J. He became interested in tremie concrete while working as a field engineer with the Frederick Snare Corp. on the Chesapeake Bay Bridge in 1950-51. One of his first duties after joining Sika was to conduct a laboratory test program on tremie concrete.

structed using permanent steel forms with reinforcing steel attached to the entire inside surface of the form. These forms were placed on prepared mats with steel bearing piles protruding into the section to receive concrete. Forms were filled with tremie concrete, thus providing direct support to the structure above the water line. Other large jobs where reinforced concrete was placed by tremie include the huge graving dock built at the New York Naval Shipyard in 1943-1944,[6] the piers on the Chesapeake Bay Bridge in 1950-1951,[7] and the piers on the Richmond-San Rafael Bridge in 1953-54.[8]

CONSTRUCTION PROCEDURE

Good construction procedures are always essential to the success of a tremie job. At least two pieces of heavy equipment are required for tremie work. One rig must hold the tremie pipe while another brings concrete to the pipe.

The tremie pipe is first sealed against water with a plug, foot valve, or burlap ball so that the concrete does not contact water until it has passed through the pipe to its final position under water. The foot of the tremie pipe is then kept continuously immersed in the fresh concrete. It is lifted only slightly, long enough for a batch to flow from the pipe. Then it is dropped back to its original position.

When the pipe is lifted out of the concrete by accident or to move the pipe to a new position, the "tremie seal" has been lost and the original pipe plugging procedure must be repeated.

Laitance usually collects in pockets at the low points on the surface of a tremie placement. It hardens more slowly than the mass of concrete and is often removed by the air-lift method before dewatering. Rapid uninterrupted placement usually results in the best uniformity and the least amount of laitance.[5,9,10]

ADVANTAGES AND DISADVANTAGES OF TREMIE CONCRETE

Use of tremie concrete for structural purposes has helped to focus much attention on this method of placement. Advantages of tremie placement include:

1. Rapid placement of huge volume at great depths
2. Dewatering unnecessary
3. Perfect curing conditions
4. Reduction or elimination of voids and honeycomb

Many engineers view the tremie method with distrust and avoid using tremie concrete whenever possible. This distrust centers around the following disadvantages:

1. Inspection of results is difficult or impossible.
2. Strength is questionable and quality is often nonuniform, particularly at extremities of flow.
3. High slumps from 6 to 9 in. are required for flow since vibration is not practical.
4. Cement content is usually increased for "safety," resulting in added cost and greater internal heat development.
5. Laitance formation is usually excessive.

TREMIE CONCRETE LABORATORY TEST PROGRAM

Chemical admixtures have been used extensively to increase quality and uniformity of structural concrete for bouyant boxes, concrete ships, floating piers, prestressed beams, lift slabs, and numerous other structures where good concrete was essential to the success of the job. It therefore seemed logical that some of the disadvantages of tremie concrete could be reduced or overcome by the proper selection of admixtures.

A laboratory test program was planned and carried out in 1954 with these objectives in mind for tremie concrete:

1. Improved flow
2. Increased uniformity
3. Decreased laitance

These objectives are interrelated since flow affects both uniformity and formation of laitance.

In preliminary work an adipic acid base retarder, a calcium chloride base accelerator, and a neutralized Vinsol resin air-entraining agent were used separately and in various combinations. The accelerator was discarded from final tests because of a rapid pattern of heat development and poor gravity flow characteristics of the mix. The mix containing only the retarder was not tested further since gravity flow characteristics were markedly improved by using the retarder in combination with controlled air entrainment.

Three mixes were subjected to comprehensive testing: (1) reference concrete; (2) air-entrained concrete (4 percent air); and (3) retarded, air-entrained concrete.

Test procedure

Equipment and materials were scaled down in size so that tests would be economically feasible. The laboratory mixes contained 9 bags of cement per cu yd with ¾-in. gravel aggregate. This high cement content was chosen to make the cement paste volume nearly equivalent to the 7-bag mix with 2-in. aggregate that is often used in tremie placement. It was felt that this mix would magnify the patterns of laitance formation and heat development.

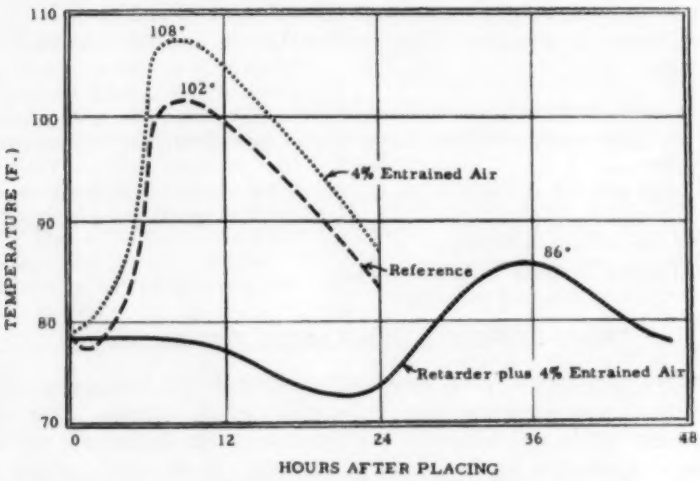


Fig. 1—Rate of internal temperature rise on laboratory tremie specimens 10 in. wide

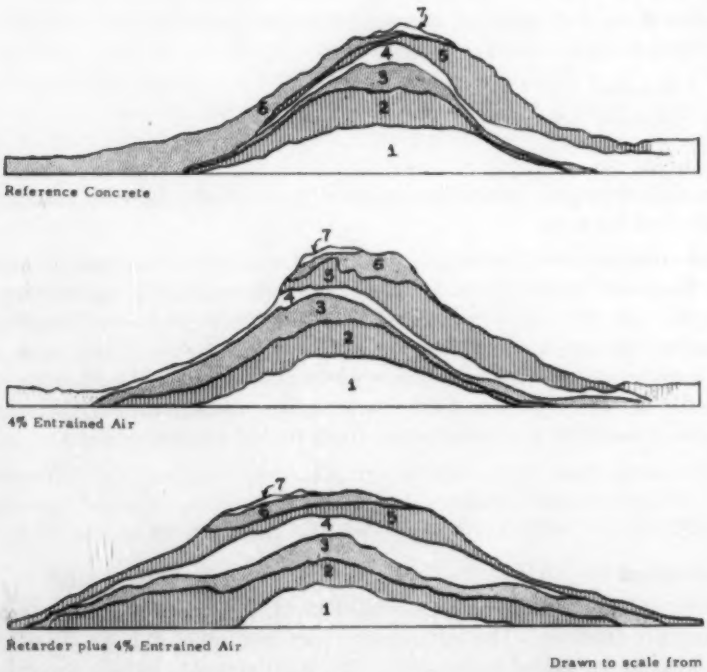


Fig. 2—Tremie flow patterns are indicated by the colored pigments used in each batch. Numbers indicate sequence of batches. Tremie pipe was at the center throughout. Thick end sections are composed of laitance and concrete of poor quality

Plywood forms 8 ft long, 2 ft high, and 10 in. wide were sealed at the joints and filled with water. The 10-in. dimension was purposely selected to restrict the flow and provide a pattern that could be easily observed.

A 3 ft long pipe, 4 in. in diameter with 20-in. funnel shaped head, was sealed at the bottom with a wood plug and placed at the center of the form. Concrete was batched in a 1-cu ft mixer. Each batch of ¾ cu ft was colored with 1½ lb of red, white, or black inert pigment. An 8-in. slump was used. Seven batches were placed at 20-min intervals. A continuously recording thermometer was inserted to a depth of 6 in. after the tremie pipe was removed. Temperature pattern varied considerably (Fig. 1).

Two days following the placement, remaining water was siphoned from the form so as not to disturb the soft laitance formation. Then forms were stripped and pattern of flow was observed (Fig. 2).

At 7 days, a chunk of concrete was removed from one face of each specimen near the center. Absorption and density of these samples were measured (Table 1).

Laitance at the end sections hardened to the consistency of chalk, but contained no aggregate. Area and depth were measured and volume was computed.

Compressive strength was estimated from Schmidt concrete test hammer rebound readings. At 7 days results were computed from 45 readings near the center of each specimen. At 90 days the hammer was used to take one

TABLE 1—SUMMARY OF LABORATORY TREMIE TESTS ON THREE MIXES

		Reference mix	Air-entrained mix	Retarded and air-entrained mix
Mix proportions:	Cement	28 lb	28 lb	28 lb
	Sand	35 lb	35 lb	35 lb
	Gravel, ¾ in.	49 lb	49 lb	49 lb
	Pigment*	1.5 lb	1.5 lb	1.5 lb
	Air-entraining resin	None	0.84 fluid oz per sack	0.5 fluid oz per sack
	Retarder (liquid)	None	None	4 fluid oz per sack
	Water added	5.2 gal. per sack	5.0 gal. per sack	4.8 gal. per sack
	Slump	8¼ in.	8 in.	8 in.
	Air content	1 percent	4¼ percent	4 percent
Flow quality:	(description)	Slippery with easy flow, not cohesive	Fatty and sticky; tendency to hold steep slope	Smooth flow with good cohesion
Temperature data:	Air temperature	78 F	81 F	95 F
	Water temperature	76 F	76 F	78 F
	Maximum internal temperature	102 F	108 F	86 F
	Time after placement	8 hr	8 hr	36 hr
	Maximum rate of increase	7 deg per hr (3 hr)	7 deg per hr (3 hr)	1.5 deg per hr (5 hr)
Laitance:	Total volume	78 cu in	53 cu in	14 cu in
Structural properties:	Absorption: 24 hr†	7.4 percent	8.1 percent	5.8 percent
	Density	147.0 lb per cu ft	143.5 lb per cu ft	147.2 lb per cu ft
	Compressive strength‡			
	7 days	4050 psi	3900 psi	4700 psi
	90 days	6850 psi	6450 psi	7175 psi
Uniformity:	Indicated strength variation from center to ends at 90 days	33.5 percent	39.5 percent	8 percent

*Pigments were red (iron oxide), white (titanium dioxide), and black (iron oxide).
†Density and absorption were measured on pieces broken from the bottom center of the hardened specimens.
‡Compressive strengths were predicted from Schmidt concrete hammer readings.

reading from each square inch of surface. Care was taken to avoid hitting the spots where 7-day readings had been made. This series of more than 900 readings on each specimen clearly indicated gradation in strength from the center to the ends (Fig. 3).

TEST RESULTS

Reference concrete

This mix was smooth flowing; it had a "slippery" quality but was not cohesive. By the time the fifth batch was placed after 1 hr and 40 min, the early batches had begun to stiffen and the pipe had to be lifted until only 5 in. remained in the plastic concrete before flow began. Colored pigments indicating flow pattern showed thin lines indicating that much cement paste had separated from the aggregate and had flowed down the slopes to the ends of the form. Internal heat developed rapidly and resulted in a maximum temperature of 102 F at 8 hr.

Compressive strengths as indicated by the test hammer varied 33.5 percent from the center to the end of the specimen. Approximately 78 cu in. of laitance was formed.

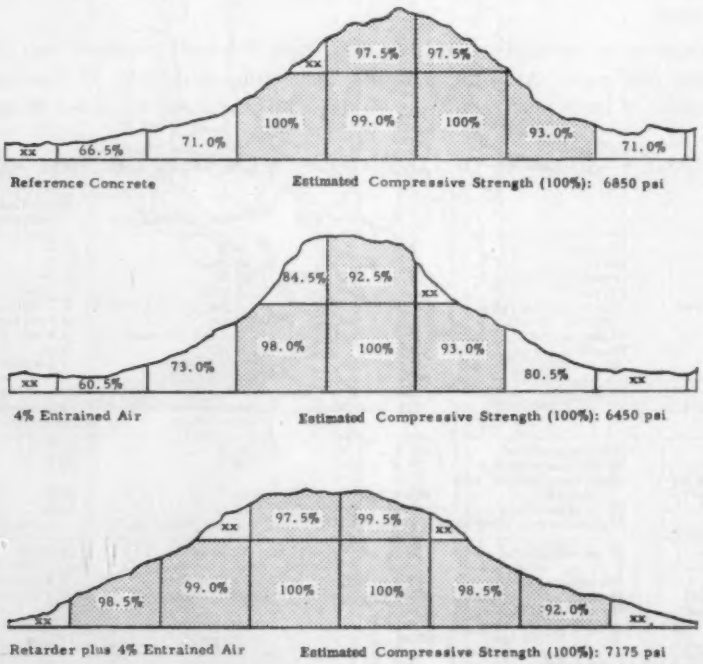


Fig. 3—Uniformity of compressive strength at 90 days was determined using the Schmidt concrete test hammer on each square inch of surface. The strongest area of 1 sq ft was assigned the value 100 percent. Areas indicated xx contained only a few readings and were not included

Air-entrained concrete

This mix was fatty and cohesive. After the third batch was placed the concrete stood on a rather steep slope. The mix did not separate and show thin lines of color as with the reference specimen. Part of the mix "rolled" down the steep slope however, washing cement from the aggregate and resulting in laitance.

Internal heat was generated rapidly, producing a maximum temperature of 108 F at 8 hr. Compressive strength as indicated by the test hammer varied 39.5 percent from the center to the end of the specimen. Approximately 53 cu in. of laitance was formed.

Retarded, air-entrained concrete

This mix was smooth flowing and cohesive. The initial set was retarded approximately 50 percent and the final three batches flowed easily with more than 10 in. of the pipe immersed in plastic concrete. The batches spread out on a gradual slope without separation. Laitance formation was approximately 14 cu in. Internal heat developed after 24 hr and the temperature climbed slowly to a maximum of 86 F at 36 hr. Compressive strength as indicated by test hammer readings varied 8 percent from the center to the ends of the specimen.

EVALUATION OF LABORATORY TESTS

Although the mix with entrained air showed improvement in cohesiveness as compared to the reference mix, the wide variation of 39.5 percent in compressive strength as indicated by hammer readings showed that air entrainment alone did not offer much improvement. Furthermore, slight reductions in maximum strength and density were recorded.

Retarded concrete containing 4 percent entrained air exhibited quite different characteristics and seemed to provide the sought-after results. There was a marked improvement in both uniformity and laitance reduction. A strength variation of only 8 percent from the center to the ends indicated by hammer readings demonstrated the superior flow quality. The usual reductions in mixing water were afforded by the retarder and by the air-entraining agent. An increase in maximum strength and a decrease in absorption were recorded, but were considered relatively unimportant to the success of a tremie project.

The retarded set and smooth flow, made possible by these admixtures, held promise of definite advantages in field work. The gentle slopes and flow for long distances which were normally possible only with fast placement rates might now be accomplished with a normal rate of placement. Tremie pipes could be spaced further apart, thus reducing both the handling and the number of pipes needed to do a job.

Because of the usual difficulty of duplicating laboratory results in the field, it was felt that a full scale field application should be studied and evaluated as an extension of the test program.

Fig. 4—A complete set of soundings was made at 5 hr and 9 hr to determine the flow and slope of concrete

FIELD EXPERIENCE WITH ADMIXTURES

On Mar. 31, 1955, a cofferdam for the Walnut Street Bridge at Wilmington, Del., was sealed with concrete containing the tested retarder and entrained air. This cofferdam was 79 ft long and 45 ft wide, with a tremie seal 12 ft thick containing 1572 cu yd of concrete.

Concrete was brought to the site in truck mixers and placed through two pipes. Soundings were made at 5 hr and at 9 hr (Fig. 4). A total of 1008 cu yd was placed without repositioning the pipes. Flow was inhibited by closely spaced H-piles at the ends of the cofferdam resulting in slightly steeper slopes (Fig. 5). Pipes were subsequently moved to other positions for placing the remaining 564 cu yd (Fig. 6).

The requirement for a 10 percent increase in cement was waived by mutual consent of the owner and consulting engineer. A standard mix was used containing 6 sacks of cement and 1½-in. aggregate with 1 lb retarder and 1 oz air-entraining agent per bag of cement. Slump varied from 8 to 9 in. Seven-day control cylinder strengths averaged 2980 psi, and 28-day strengths averaged 4620 psi (Table 2).

After 2 weeks the cofferdam was dewatered and the surface observed. Laitance deposits in low areas were slight with no deep pockets and a maximum accumulation of only 2 in.

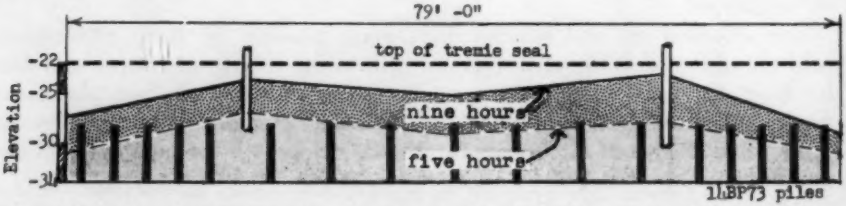
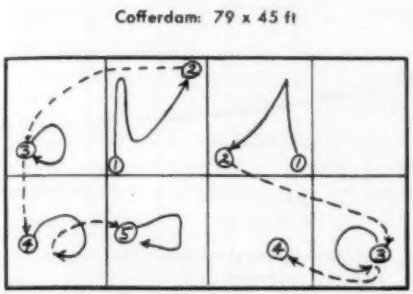


Fig. 5—Section at longitudinal center line of cofferdam, Walnut Street Bridge. Flow pattern at 5 hr and 9 hr shows gentle slopes at the center and slightly steeper slopes at the end where piles are closely spaced


Cofferdam: 79 x 45 ft
Tremie Pipe Positions
Position 1 from start to 9 hr
Position 2 from 9 to 11 hr
Positions 3, 4, and 5 from 11 to 17 hr

Elapsed time, hr	Cu yd per hr	Cu yd, cumulative
1	150	150
2	121½	271½
3	104½	376
4	104½	480½
5	95½	576
6	120	696
7	114	810
8	96	906
9	102	1008
10	72	1080
11	96	1176
12	114	1290
13	108	1398
14	60	1458
15	54	1512
16:50 min.	60	1572—Total

Fig. 6—Rate of placement and pipe positions at Walnut Street Bridge

The tremie surface was cored at six points to a depth of 14 in. to determine the condition of this upper stratum of concrete where quality is likely to be poor. Cores were 4 in. in diameter and were cut off to an 8-in. length for testing. Core strength of this surface layer averaged 2975 psi at 28 days.

Internal temperature

Internal temperature for mass concrete has been studied largely in the low cement content mixes used in dams. These temperatures will range from 100 to 122 F depending on the thickness of the section.[11,12] Temperature in high cement content tremie mixes will run 20 to 40 F higher and has been recorded at 150 F.[13]

On the Connecticut Turnpike bridge across the Housatonic River at Bridgeport, the retarding agent and the air-entraining agent were used with 6.3 bags

TABLE 2—COMPRESSIVE STRENGTH OF CONTROL CYLINDERS AT WALNUT STREET BRIDGE

Cylinders cast 3/31/55 at	Slump, in.	Air, percent	7-day compressive strength, psi		28-day compressive strength, psi	
			Individual cylinders	Average	Individual cylinders	Average
7:00 a.m.	8½	5.3	3381 3381 3204	3320	4951 5164 4810	4980
10:20 a.m.	9	3.3	3091 3148 3236	3160	5164 5305 5005	5160
2:20 p.m.	8	5.0	3063 2529 3042	2880	4456 4173 4350	4330
6:20 p.m.	8½	5.4	2745 2122 2811	2560	3926 3982 4089	4000
Job averages	8½	4.75		2980		4620

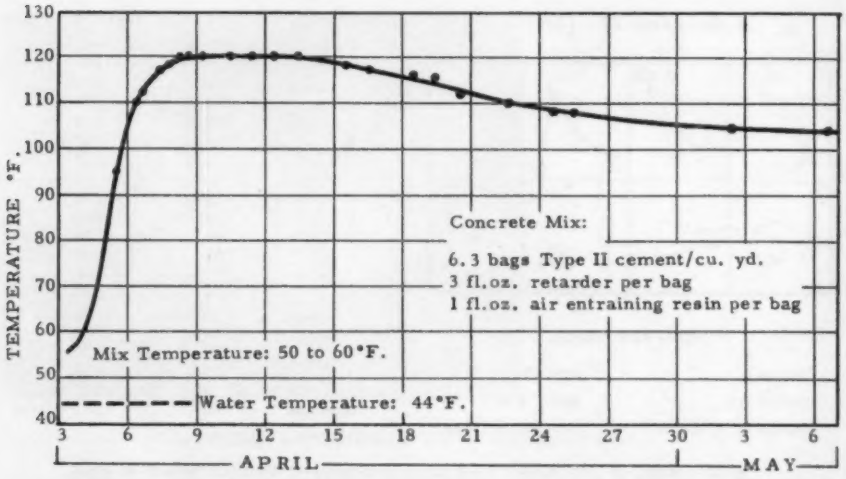


Fig. 7—Internal temperatures at north center of tremie seal on Connecticut Turnpike bridge at Bridgeport. This placement contained 2812 cu yd of concrete and was placed against sloping bedrock. Thickness averaged 27 ft

of Type II cement in a tremie seal. A total of 2800 cu yd was placed in 2 days. Internal temperature reached 110 F on the third day and rose to a maximum of 120 F on the fifth day. The temperature was steady until the tenth day and then slowly declined to 104 F after 1 month (Fig. 7).

The retarding agent plus the air-entraining agent were accepted to provide the safety factor so that cement content was not increased to 7.15 bags as originally planned. Thus internal temperature was benefited by both a lower cement content and chemically retarded rate of heat development.

Extra retardation

During construction of concrete ice breakers for the Tappan Zee Bridge (on the Hudson River in New York), concrete was placed in 10-ft lifts at 48-hr intervals because the sheet piling formwork was not designed for continuous placement. Double the normal proportion of retarder was used in the top 2 ft of each lift. This assured slow hydration with no appreciable heat development for the 48-hr interval between lifts. Hence, each lift was placed on the previous one before internal heat was generated, providing better opportunity for chemical bond to develop between lifts.

CONCLUSION

Tremie concrete can be controlled to give more dependable results by use of admixtures. A retarder plus 4 percent entrained air provided best results in laboratory tests. Cohesiveness and gravity flow qualities were noticeably improved. This provided more uniform strength throughout the specimen.

Laitance was reduced. Initial set was retarded and internal heat developed at a slower rate.

Reports and data from field projects using retarder with air-entraining agent tend to substantiate conclusions based on laboratory results. Improved gravity flow and cohesiveness resulted in a minimum of laitance. Gentle slopes were obtained even where steel bearing piles were closely spaced. Cylinder strengths for this high slump concrete averaged more than 4500 psi at 28 days. Core strengths at the top surface were also satisfactory.

Where retardation and air entrainment were adopted instead of an arbitrary increase in cement content for tremie work, internal heat was generated at a lower rate and maximum temperature was lower than would otherwise have been observed.

Use of the admixtures investigated has been shown to produce a more uniform tremie concrete with lower heat generation and with less restriction on the rate of placing than if extra cement had been used to achieve somewhat equivalent quality.

ACKNOWLEDGMENTS

Laboratory tests were conducted using the facilities of Sika Chemical Corp., Passaic, N. J. The author received valuable suggestions and assistance from Emil Schmid and Raymond J. Schutz throughout the test program.

Field test data were obtained through the cooperation of the owners, consulting engineers, and contractors on various field projects referred to in the text.

Walnut Street Bridge: owner, Delaware State Highway Department; consulting engineers, Parsons, Brinckerhoff, Hall and Macdonald; contractor, A. S. Wikstrom.

Housatonic River Bridge: owner, Connecticut Turnpike Commission; consulting engineers, Ammann and Whitney; contractor, A. S. Wikstrom.

Ice breakers at Tappan Zee Bridge: owner, New York Thruway Commission; consulting engineers, Madigan-Hyland; contractor, J. Rich Steers, Inc.

REFERENCES

1. Burnham, A. K., Jr., "Underwater Concreting," *Construction Methods and Equipment*, V. 37, No. 6, June 1955, pp. 99-112.

2. Kinipple, Walter Robert, "Concrete Work Under Water," *Proceedings*, Institution of Civil Engineers (London), V. 87, 1886, pp. 65-73.

3. Heude, H., News Item, *Engineering News*, June 13, 1885, p. 381.

4. Ward, W. H., Letter to Editor, *Engineering News*, Mar. 1, 1894, p. 181.

5. Halloran, P. J., and Talbot, K. H., "The Properties and Behavior Underwater of Plastic Concrete," ACI JOURNAL, V. 14, No. 6, June 1943 (*Proceedings* V. 39), pp. 461-492; discussion by F. R. Harris and A. Tauber, Nov. Supplement 1943 (*Proceedings* V. 39), p. 492-1.

6. Angas, W. Mack, Shanley, E. M., and Erickson, J. A., "Concrete Problems in the Construction of Graving Docks by the Tremie Method," ACI JOURNAL, V. 15, No. 4, Feb. 1944 (*Proceedings* V. 40), pp. 249-320.

7. Lockwood, R. K., "Ingenuity and Heavy Equipment Combine to Build 4.3 Mile Chesapeake Bay Bridge," *Civil Engineering*, V. 21, No. 5, May 1951, pp. 48-51.

8. Gerwick, Ben C., Jr., "Hollow Precast Concrete Units of Great Size Form Bridge Substructure," *Civil Engineering*, V. 24, No. 4, Apr. 1954, pp. 59-63.

9. Colby, W. S., "Design and Construction of a Circulating Water Intake," ACI JOURNAL, V. 21, No. 7, Mar. 1950 (*Proceedings* V. 46), pp. 497-508.

10. Anderson, Arthur R., "A Study of Subaqueous Concrete," ACI JOURNAL, V. 8, No. 3, Jan.-Feb. 1937 (*Proceedings* V. 33), pp. 339-346.

11. Burks, S. D., "The Five-Year Temperature Record of a Thin Concrete Dam," ACI JOURNAL, V. 19, No. 1, Sept. 1947 (*Proceedings* V. 44), pp. 65-76.

12. Carlson, Roy W., "Temperatures and Stresses in Mass Concrete," ACI JOURNAL, V. 9, No. 4, Mar.-Apr. 1938 (*Proceedings* V. 34), pp. 497-515.

13. Stanton, Thomas E., Jr., "Cement and Concrete Control: San Francisco-Oakland Bay Bridge," ACI JOURNAL, V. 7, No. 1, Sept.-Oct. 1935 (*Proceedings* V. 32), pp. 1-27.

Received by the Institute June 16, 1958. Title No. 55-54 is a part of copyrighted Journal of the American Concrete Institute, V. 30, No. 8, Feb. 1959 (Proceedings V. 55). Separate prints are available at 50 cents.

American Concrete Institute, P. O. Box 4754, Redford Station, Detroit 19, Mich.

Discussion of this paper should reach ACI headquarters in triplicate by May 1, 1959, for publication in the Part 2, September 1959 JOURNAL.

Title No. 55-55

LONGITUDINAL FORCES resulting from live load on a highway bridge deck and from bearing friction at supports of bridge girders produce shear, bending, and torsion in the supporting pier. Messrs. Au and Fok analyze a type of pier often used in highway bridges, namely the portal frame fixed at supports, subject to such forces.

Loading is assumed unsymmetrical with respect to the center line of the portal frame. Analysis by moment distribution is extended to include the effects of torsion. The advantages and limitations of the method of analysis are discussed, and the solution for frames with prismatic members is formulated.

effects of longitudinal forces on portal frame supporting a highway bridge deck

By TUNG AU and THOMAS D. Y. FOK

IN THE DESIGN of concrete piers supporting a highway bridge deck, AASHO specifications[1] require that the effect of a longitudinal force of 5 percent of the live load in all lanes shall be considered as acting 4 ft above the floor, and that adequate provisions shall be made for the longitudinal force due to friction at expansion bearings. These forces act normal to the plane of the supporting pier and produce torsion as well as bending in its members. A general procedure for the analysis of laterally loaded plane structures has been presented by Baron and Michalos.[2] However, its applications to a variety of actual problems have been handicapped by mathematical complexities. The current practice of design of highway bridge piers seems to be overconservative for lack of a simple and yet precise solution for the effect

of the longitudinal forces. This paper attempts to present a rational method of analysis which will satisfy such need.

The analysis is for portal frames fixed at supports as shown in Fig. 1(a), but the method may be extended to other types of frames such as those shown in Fig. 1(b) and 1(c). The forces normal to the plane of the frame are, in general, unsymmetrical about the center line of the frame due to the location of the roadway on bridge deck and the spacing of the bridge girders. These forces do not act on the axis of the frame but can be transformed into forces acting there plus moments about the same axis. Hence, the basic problem can be conceived as the analysis of a portal frame acted on by an unsymmetrical force normal to the plane of the frame and an unsymmetrical moment about the axis of the frame girder. The total effects of all longitudinal forces are then obtained by superposition.

GENERAL CONSIDERATIONS

Basic concept

The general case of a portal frame fixed at supports involves six reactions at each support, making a total of twelve unknowns for the entire frame. If the direction of the bridge girder is skew, the longitudinal force is inclined rather than normal to the plane of the frame. However, such force can be resolved into two components, one normal and the other tangential to that plane, the tangential component being horizontal also. On the other hand, if the bridge girders are placed at a slope, the longitudinal force again can be resolved into two components, one normal and the other tangential to the plane of frame, the tangential component being vertical. These tangential components, both horizontal and vertical, can readily be treated by ordinary methods of analyzing plane structures and will not be dealt with in this paper. Hence, there will only be six reactions for the structure due to loads normal to the plane of the frame.

For the sake of clarity of illustration, the portal frame is rotated 90 deg so that the axis of the frame lies in a horizontal xy-plane as shown in Fig. 2. Hence, the longitudinal force P acts at point E in the direction of the z-axis, and the moment acts about axis BC which is parallel to the x-axis. Under the given loading condition, there are three unknown reactions at each of the

Two engineering educators, TUNG AU and THOMAS D. Y. FOK are both registered professional engineers and members of the American Concrete Institute. ● Dr. Au, associate professor of civil engineering, Carnegie Institute of Technology, Pittsburgh, was previously on the staff of the University of Detroit, and has done design work for a number of engineering and architectural firms. ● Dr. Fok is associate professor of engineering, Youngstown University, Youngstown, Ohio. Prior to assuming his teaching duties in 1958 he was structural engineer for Richardson, Gordon and Associates in Pittsburgh.

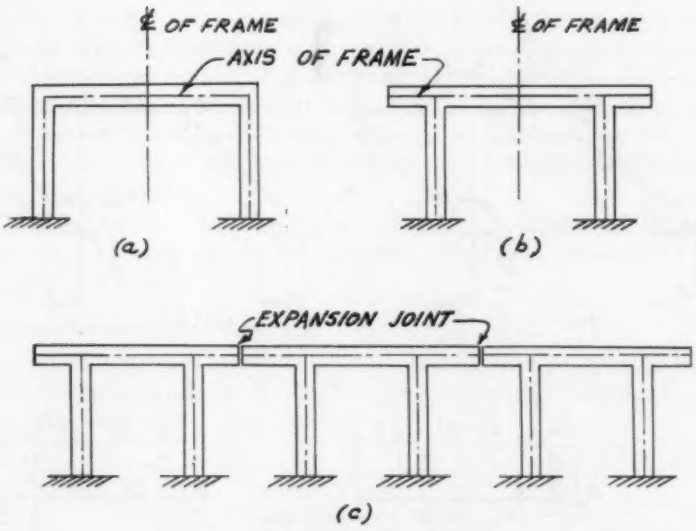


Fig. 1—Types of portal frames

two supports A and D, i.e., the bending moments M_{xa} and M_{xd}, the torsional moments M_{ya} and M_{yd}, and the vertical reactions R_{za} and R_{zd}. Positive directions of the reactions are indicated in Fig. 2.

Since the given force P and the given moment M are not symmetrical with respect to the center line of the frame, each of them can be treated as the combination of a symmetrical and an antisymmetrical case as represented by Fig. 3(a), 3(b), 3(c), and 3(d), respectively, the sign convention of the re-

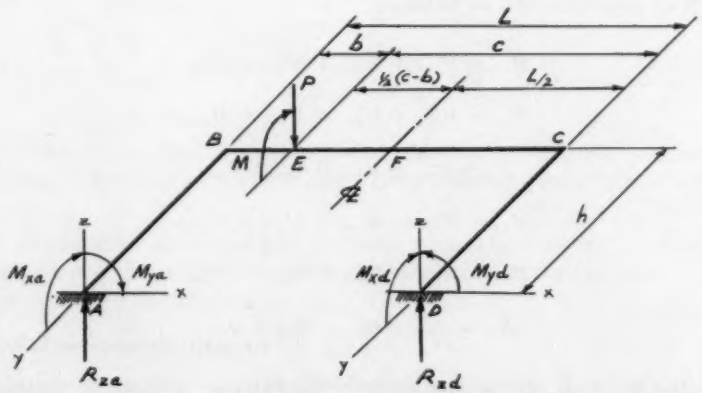


Fig. 2—Loads and reactions on the frame. Frame rotated 90 deg so that its axis lies in the horizontal plane

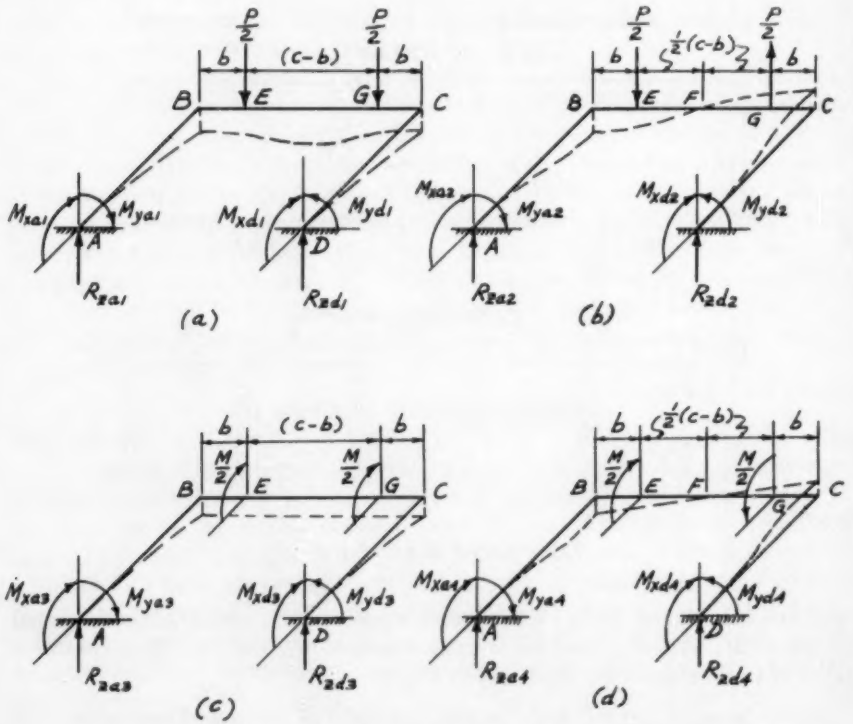


Fig. 3—Symmetrical and antisymmetrical cases of forces and moments

actions being the same as Fig. 2. The solution of the problem will finally be obtained by superposition as follows:

$$M_{xa} = M_{xa1} + M_{xa2} + M_{xa3} + M_{xa4} \quad \text{(1a)}$$

$$M_{ya} = M_{ya1} + M_{ya2} + M_{ya3} + M_{ya4} \quad \text{(1b)}$$

$$R_{za} = R_{za1} + R_{za2} + R_{za3} + R_{za4} \quad \text{(1c)}$$

$$M_{xd} = M_{xd1} + M_{xd2} + M_{xd3} + M_{xd4} \quad \text{(1d)}$$

$$M_{yd} = M_{yd1} + M_{yd2} + M_{yd3} + M_{yd4} \quad \text{(1e)}$$

$$R_{zd} = R_{zd1} + R_{zd2} + R_{zd3} + R_{zd4} \quad \text{(1f)}$$

Now, the problem can be analyzed by the familiar concept of distribution of bending and torsional moments in a simple and straightforward manner.[3,4] For the case of symmetrical moments as in Fig. 3(c), the static conditions

alone are sufficient for its solution; and for the case of symmetrical forces as in Fig. 3(a), only one distribution of moments in each plane is required. For the antisymmetrical loading, Fig. 3(b) and (d), the joints of the frame can be considered at first as being held in position by vertical holding forces, and the moments distributed accordingly. When these holding forces are released, corrections are made for the bending and torsional moments developed by the resulting displacements.

The method of least work has been deliberately avoided in approaching the problem, but has been used for checking the results obtained for frames with prismatic members.

Conditions of static equilibrium

Three static equations can be written for each of the symmetrical and antisymmetrical configurations in Fig. 3. Then, from the conditions of static equilibrium, one obtains:

$$\left.\begin{aligned} R_{za1} &= R_{zd1} = P/2 \\ M_{xa1} &= M_{xd1} = -Ph/2 \\ M_{ya1} &= M_{yd1} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\left.\begin{aligned} R_{za2} &= -R_{zd2} \\ M_{xa2} &= -M_{xd2} \\ M_{ya2} &- \frac{P}{2}(c-b) = M_{yd2} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$\left.\begin{aligned} R_{za3} &= R_{zd3} = 0 \\ M_{xa3} &= M_{xd3} = -M/2 \\ M_{ya3} &= M_{yd3} = 0 \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$\left.\begin{aligned} R_{za4} &= -R_{zd4} \\ M_{xa4} &= -M_{xd4} \\ M_{ya4} &= -M_{yd4} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Hence, Case (c) is statically determinate, Case (a) is statically indeterminate to one degree, and both Cases (b) and (d) are statically indeterminate to three degrees.

One can take advantage of the symmetrical and antisymmetrical configurations and solve the unknowns in only one-half of the frame. The other unknowns will then be obtained by Eq. (2) to (5).

Method of moment distribution

When the method of moment distribution is extended to include the effects of torsion, the fixed-end moments, stiffnesses, and carry-over factors in torsion as well as in bending must be found. In bending, these constants are well

known for prismatic members and can be obtained by column analogy for haunched members.[3] In torsion, however, these terms need be examined more closely.

The fixed-end moments of a member in torsion can be obtained from the consideration of the continuity condition, i.e., same angle of twist for segments on either side of the applied twisting moment. If more than one moment is applied to the member, the total effects may be added by superposition. The stiffness in torsion may be defined as the twisting moment required to produce a unit angle of twist between the two ends of a member. From statics, the carry-over factor in torsion is evidently unity in the opposite direction. For prismatic members of solid cross sections, such as circles, ellipses, and rectangles, the fixed-end moments are inversely proportional to the lengths of the segments on each side of the applied twisting moment. With the exception of circular members, the sections of a member are warped during twisting. The torsional stiffness equals to GJ'/h where h is the length of the member, G is the modulus of rigidity, and GJ' is known as torsional rigidity. For a circular section, $J' = J$, which is the polar moment of inertia of the section; for an elliptical section, St. Venant's formula[5] gives $J' = A^4/4\pi^2 J$ where A is the area of the section. For rectangular section, J' can be computed approximately by the formula for an ellipse, or more exactly by membrane analogy which leads to a solution by infinite series (Reference 5, p. 278). For cases in which one or more cross sections of a member are caused to remain plane, the warping constraint can be taken into account by means of a correction factor, but its effect is negligible for elliptical or rectangular members if the cross-sectional dimensions are small in comparison with the length of the member (Reference 5, p. 302). For members of variable cross sections, neither the angle of twist nor the torsional stiffness can easily be obtained. This restricts somewhat the application of the proposed method to nonprismatic members.

Due to the nature of this problem, only one distribution of moments in each plane is necessary in all operations. For Case (a), the static conditions are also satisfied after one distribution. In each of the antisymmetrical cases [Fig. 3 (b) and (d)], however, one distribution results in an unbalanced lateral force which must be eliminated by "lateral-sway" correction. The final reactions are obtained by superposition.

Notation

All symbols used are defined here unless otherwise noted.

A = area of the section of a member

b, c = length of segments in Member BC ($c > b$)

D^B = bending distribution factor (Double subscripts may be added such as $D^B{}_{ba}$ which means distribution from B to A of Member AB.)

D^T = torsional distribution factor (Double subscripts may be added as above.)

E = modulus of elasticity

G = modulus of rigidity

h = length of Members AB and CD

I = moment of inertia (Subscript h refers to Member AB and L refers to Member BC.)

J = polar moment of inertia of the section

J' = a quantity related to torsional rigidity, with units of length to the fourth power (Subscript h refers to Member AB and L refers to Member BC.)

K = bending stiffness (Double subscripts may be added such as K_{ba} which means stiffness at B for Member BA.)

K' = torsional stiffness (Double subscripts may be added as above.)

L = length of Member BC

m, m' = fixed-end moments at B for Members BC and BA respectively, for a deflection Δ at B assumed for lateral-sway correction

M_x = moment about x-axis (Same term with a second subscript such as M_{xa} means this moment at A.)

M_y = moment about y-axis (Same term with a second subscript such as M_{yb} means this moment at B.)

M^F_{xbc} = fixed-end moment about x-axis (in torsion) at End B of Member BC

M^F_{ybc} = fixed-end moment about y-axis (in bending) at End B of Member BC

M = given moment about Member BC of the frame

P = given force applied on Member BC and normal to the plane of the frame

Q = EI_L/GJ'_h

Q' = EI_h/GJ'_L

R_z = reaction in z-direction. (Same term with a second subscript such as R_{za} means this reaction at A.)

S = $I_L h^2/I_h L^2$

T, U = constants defined by Eq. (7a) and (7b) for lateral-sway correction

V = unbalanced vertical force in lateral-sway correction (Double subscripts may be added such as V_{bc} which means force at End B of Member BC.)

FRAMES WITH PRISMATIC MEMBERS

Constants for moment distribution

For the prismatic members of a portal frame, the fixed-end moments, stiffnesses, and carry-over factors for various loading conditions are formulated in standard textbooks on statically indeterminate structures.[3,4] It is sufficient to point out here only the modification made to simplify the moment distributions in this problem.

With reference to Fig. 4, Ends B and C of Member BC are locked temporarily in determining the fixed-end moments. For the symmetrical Case (a), the fixed-end moments of Member BC are obtained in the usual manner, but the stiffness K of the same member is determined by applying equal moments at Ends B and C to cause unit rotation at both ends. Thus, $K = 2EI_L/L$ and there will be no carry-over of fixed-end moment from either end to the other. For the antisymmetrical Cases (b) and (d), the center F of Member BC has no displacement. Hence, only the BF-half of Member BC need be considered if Point F is assumed to be a fictitious support, hinged for bending as in Case (b) and fixed for torsion as in Case (d). These prescribed support conditions of F result in fixed-end moments in BC identical to those obtained by the ordinary method, and the bending and torsional stiffnesses of member BF are computed accordingly.

The distribution factors are obtained from the proper combinations of stiffnesses of members meeting at Joint B. In all cases shown in Fig. 4, a bend-

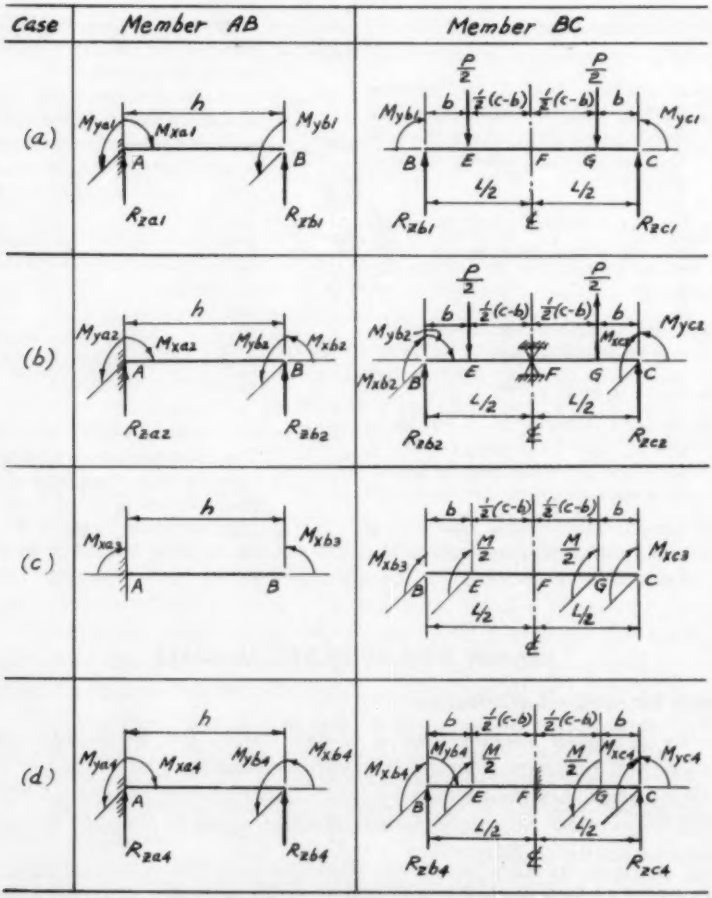


Fig. 4—Free body diagrams of AB and BC

ing moment in one member is transmitted to another member as a torsional moment and vice versa. The distribution factor, therefore, involves the bending stiffness of one member and the torsional stiffness of another member.

All these constants pertaining to the problem—fixed-end moments, stiffnesses, distribution factors, and carry-over factors—are listed in Table 1.

Distribution of moments

Moment distributions for Cases (a), (b), and (d) are carried out in Fig. 5. Only one distribution in each plane is necessary for all cases.

In examining the vertical forces, however, only Case (a) satisfies the static conditions since $V_{bc1} = P/2$ which checks with $R_{za1} = P/2$ if the free body diagram of Member AB is considered. Thus,

$$M_{ca1} = -\frac{Pbc}{2(L + 2hQ)} \qquad (6)$$

In Case (b), V_{bc2} is an unbalanced vertical force at Joint B resulting from the moment at B and the applied force $P/2$ at E. Thus,

$$V_{bc2} = \frac{P(c - b)(L^2 + 6hLQ + 2bc)}{2L^2(L + 6hQ)}$$

Similarly, in Case (d), V_{ba4} is an unbalanced vertical force at B resulting from the moments at A and B of Member AB.

$$V_{bc4} = \frac{3M(c - b)Q'}{2h(h + 2LQ')}$$

TABLE 1—CONSTANTS FOR MOMENT DISTRIBUTION

Constant		Case (a)	Cases (b) and (d)
Fixed-end moments	Bending	$M^F_{bc} = -\frac{Pbc}{2L}$	$M^F_{bc} = -\frac{Pbc(c-b)}{2L^2}$, (b) *only*
	Torsion	—	$M^F_{abc} = -\frac{M(c-b)}{2L}$, (d) *only*
Stiffnesses	Bending	—	$K_{ba} = \frac{4EI_h}{h}$
		$K_{bc} = \frac{2EI_L}{L}$	$K_{bc} = \frac{3EI_L}{L/2} = \frac{6EI_L}{L}$
	Torsion	$K'_{ba} = \frac{GJ'_h}{h}$	$K'_{ba} = \frac{GJ'_h}{h}$
		—	$K'_{bc} = \frac{GJ'_L}{L/2} = \frac{2GJ'_L}{L}$
Distribution factors	Bending in BC	$D^B_{bc} = \frac{K_{bc}}{K'_{ba} + K_{bc}} = \frac{2hQ}{L + 2hQ}$	$D^B_{bc} = \frac{K_{bc}}{K'_{ba} + K_{bc}} = \frac{6hQ}{L + 6hQ}$
	Torsion in BA	$D^T_{ba} = \frac{K'_{ba}}{K'_{ba} + K_{bc}} = \frac{L}{L + 2hQ}$	$D^T_{ba} = \frac{K'_{ba}}{K'_{ba} + K_{bc}} = \frac{L}{L + 6hQ}$
	Bending in BA	—	$D^B_{ba} = \frac{K_{ba}}{K_{ba} + K'_{bc}} = \frac{2LQ'}{h + 2LQ'}$
	Torsion in BC	—	$D^T_{bc} = \frac{K'_{bc}}{K_{ba} + K'_{bc}} = \frac{h}{h + 2LQ'}$
Carry-over factors	Bending	Far end fixed	Carry-over factor = $-\frac{1}{2}$ for all cases
		Far end hinged	Carry-over factor = 0 for all cases
	Torsion	(Far end fixed)	Carry-over factor = -1 for all cases

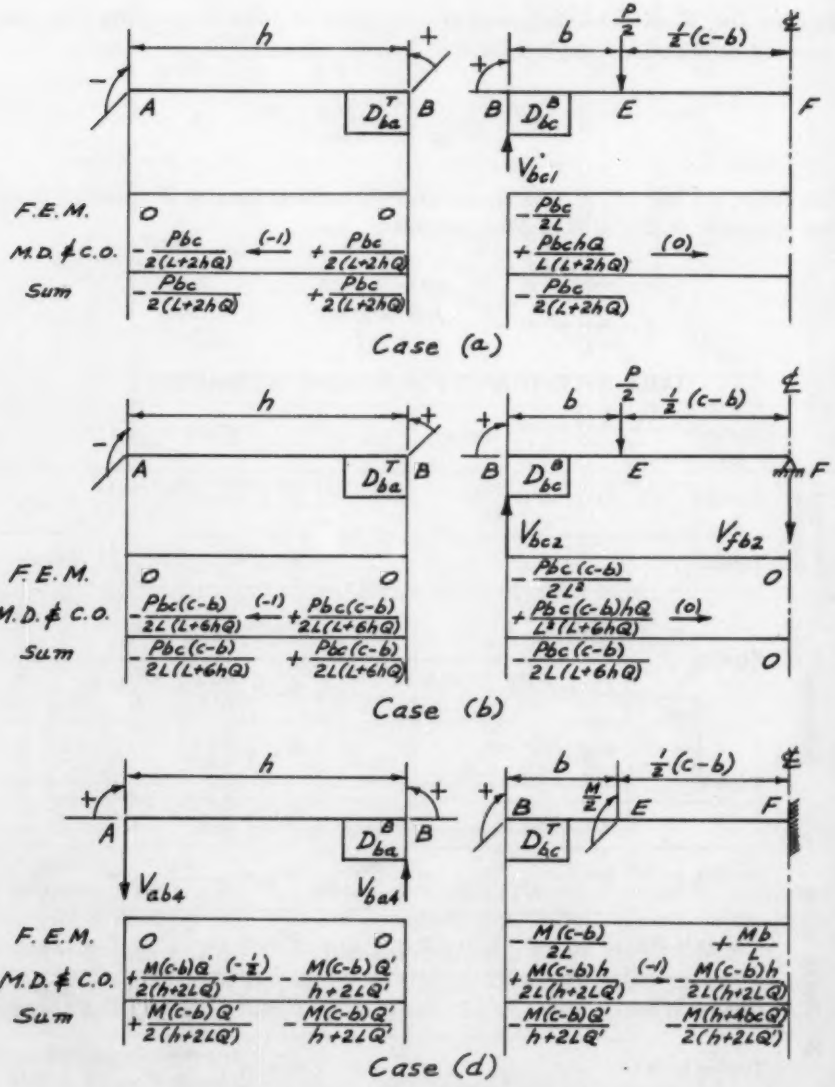


Fig. 5—Moment distribution for Cases (a), (b), and (d)

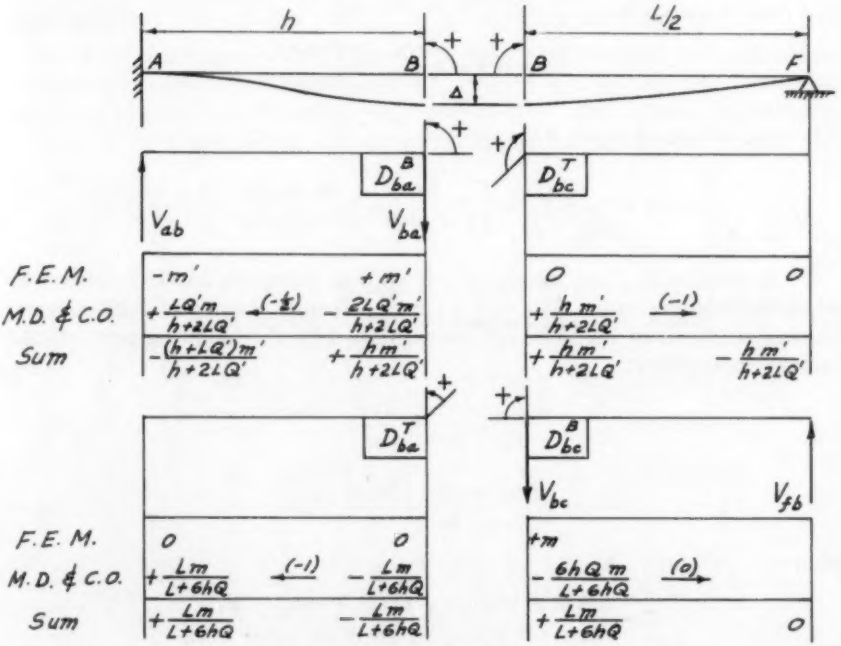


Fig. 6—Moments due to lateral sway

As an analogy to the sidesway correction of plane structure, these unbalanced vertical forces can be considered as holding forces in preventing the lateral displacement of Joint B. Since the vertical holding forces at Joint B must be released and Joint B deflects vertically, the moment obtained previously from one distribution must be corrected for the lateral sway of the frame.

"Lateral-sway" correction

Fig. 6 shows the distribution of moments due to a deflection Δ at Joint B. The fixed-end moments at B in Members BC and BA are, respectively, as follows:

$$m = M^F_{ybc} = \frac{3EI_L\,\Delta}{(L/2)^2} = \frac{12EI_L\,\Delta}{L^2}$$

$$m' = M^F_{yba} = \frac{6EI_h\,\Delta}{h^2}$$

Since $m = (2I_Lh^2/I_hL^2)m' = 2Sm'$, m may be determined if m' is arbitrarily assumed. The vertical forces resulting from m and m' are also arbitrary but can be expressed in terms of m and m'. Thus, from Member BC,

$$V_{bc} = V_{fb} = \frac{2m}{L + 6hQ}$$

and from Member BA,

$$V_{ba} = V_{ab} = \frac{(2h + LQ')\, m'}{h\,(h + 2LQ')}$$

The total effects at Joint B become:

$$V_b = V_{bc} + V_{ba} = \left[\frac{2}{L + 6hQ} + \frac{2h + LQ'}{2Sh\,(h + 2LQ')}\right] m$$

To determine the true moments and vertical reactions due to lateral-sway when the holding forces V_{bc2} and V_{ba4} are released, the set of moments and vertical reactions in Fig. 6 should be multiplied by the following proportional factors respectively:

$$\frac{V_{bc2}}{V_b} = \frac{TP}{2m'} = \frac{STP}{m} \qquad (7a)$$

$$\frac{V_{bc4}}{V_b} = \frac{UM}{2m'} = \frac{SUM}{m} \qquad (7b)$$

where

$$T = \frac{h\,(h + 2LQ')\,(c - b)\,(L^3 + 6hLQ + 2bc)}{L^2\left[4Nh\,(h + 2LQ') + (2h + LQ')\,(L + 6hQ)\right]}$$

$$U = \frac{3\,(c - b)\,(L + 6hQ)\,Q'}{4Nh\,(h + 2LQ') + (2h + LQ')\,(L + 6hQ)}$$

Consequently, the corrected moments and vertical reactions for Cases (b) and (d) pertinent to the problem are as follows:

$$M_{xc2} = -\frac{PT\,(h + LQ')}{2\,(h + 2LQ')} \qquad (8a)$$

$$M_{yc2} = -\frac{Pbc\,(c - b)}{2L\,(L + 6hQ)} + \frac{PLST}{L + 6hQ} \qquad (8b)$$

$$R_{xc2} = +\frac{PT\,(2h + LQ')}{2h\,(h + 2LQ')} \qquad (8c)$$

$$M_{xc4} = +\frac{M\,(c - b)\,Q'}{2\,(h + 2LQ')} - \frac{MU\,(h + LQ')}{2\,(h + 2LQ')} \qquad (9a)$$

$$M_{yc4} = +\frac{MLSU}{L + 6hQ} \qquad (9b)$$

$$M_{xc4} = -\frac{3M\,(c - b)\,Q'}{2h\,(h + 2LQ')} + \frac{MU\,(2h + LQ')}{2h\,(h + 2LQ')} \qquad (9c)$$

Final solution

The general solution of the problem can finally be obtained by substituting the moments and vertical reactions of Eq. (6), (8), and (9) into Eq. (2) to (5), which are in turn substituted into Eq. (1a) to (1f). The results are expressed in terms of the given load P and the given moment M as follows:

$$M_{xa} = -\left[h + \frac{(h + LQ')\,T}{(h + 2LQ')}\right]\frac{P}{2} - \left[1 + \frac{(h + LQ')\,U - (e - b)\,Q'}{(h + 2LQ')}\right]\frac{M}{2} \quad \text{(10a)}$$

$$M_{ya} = -\left[\frac{bc}{(L + 2hQ)} - \frac{2L^2\,ST - bc\,(e - b)}{L\,(L + 6hQ)}\right]\frac{P}{2} + \left[\frac{LSU}{L + 6hQ}\right]M \quad \text{(10b)}$$

$$R_{za} = \left[1 + \frac{(2h + LQ')\,T}{h\,(h + 2LQ')}\right]\frac{P}{2} + \left[\frac{(2h + LQ')\,U - 3\,(e - b)\,Q'}{2h\,(h + 2LQ')}\right]M \quad \text{(10c)}$$

$$M_{xd} = -\left[h - \frac{(h + LQ')\,T}{(h + 2LQ')}\right]\frac{P}{2} - \left[1 - \frac{(h + LQ')\,U - (e - b)\,Q'}{(h + 2LQ')}\right]\frac{M}{2} \quad \text{(10d)}$$

$$M_{yd} = -\left[\frac{bc}{(L + 2hQ)} - \frac{2L^2\,ST - bc\,(e - b)}{L\,(L + 6hQ)} + (e - b)\right]\frac{P}{2} - \left[\frac{LSU}{L + 6hQ}\right]M \quad \text{(10e)}$$

$$R_{zd} = \left[1 - \frac{(2h + LQ')\,T}{h\,(h + 2LQ')}\right]\frac{P}{2} - \left[\frac{(2h + LQ')\,U - 3\,(e - b)\,Q'}{2h\,(h + 2LQ')}\right]M \quad \text{(10f)}$$

While Eq. (10a) to (10f) may seem long and cumbersome, the results of a given problem can be obtained by straightforward substitution of numerical values into the equations. This is not much of an effort when one considers the other more elaborate alternatives, such as carrying out the moment distribution directly each time, or obtaining the solution by Castigliano's theorem. With the aid of digital computer, the general equations seem to be even more attractive.

NUMERICAL EXAMPLE

A brief numerical example with dimensions shown in Fig. 7 is given here.

Find the effects of the longitudinal force due to the live load acting on the I-beam stringer indicated in Fig. 7. Assume that the total live load reaction of the stringer on the frame is 100 kips, 5 percent of which is 5 kips acting 4 ft above the bridge floor. Assume a depth of 4 ft to take into account the slab thickness, the stringer depth, and the height of bearing. The longitudinal force of 5 kips is then acting 4 + 4 + 2 = 10 ft above the center line of the pier girder, causing a moment of 5 × 10 = 50 ft-kips. For concrete, E/G is taken to be 2.35. Then

$$I_h = \tfrac{1}{12} \times 3 \times 3^3 = 6.75 \text{ ft}^4 \qquad I_L = \tfrac{1}{12} \times 3 \times 4^3 = 16.0 \text{ ft}^4$$

$$J_h = 2 \times 6.75 = 13.5 \text{ ft}^4 \qquad J_L = \tfrac{1}{12}\,(3 \times 4^3 + 4 \times 3^3) = 25.0 \text{ ft}^4$$

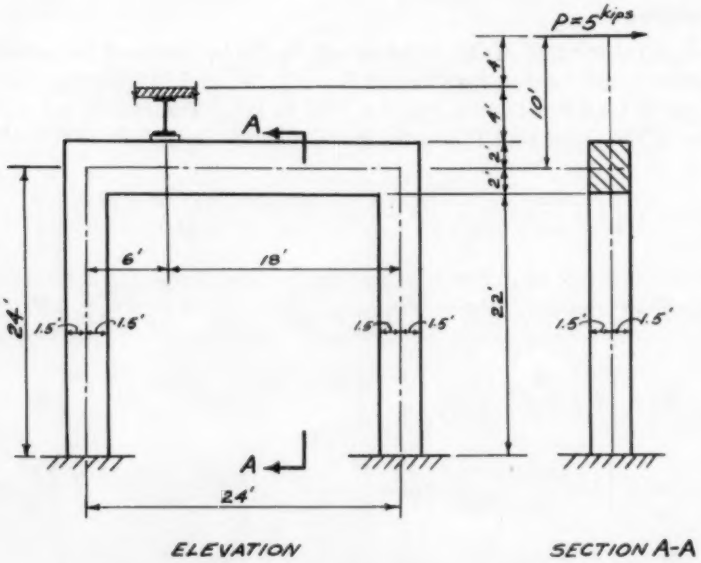


Fig. 7—Portal frame dimensions and loading for numerical example

$$J_h' = \frac{A_h^4}{4\pi J_h} = \frac{9^4}{4\pi \times 13.5} = 38.6 \text{ ft}^4 \qquad J_L' = \frac{A^4_L}{4\pi J_L} = \frac{(12)^4}{4\pi \times 25} = 66.0 \text{ ft}^4$$

$$Q = \frac{E I_L}{G J_h'} = \frac{2.35 \times 16}{38.6} = 0.975 \qquad Q' = \frac{E I_h}{G J_L'} = \frac{2.35 \times 6.75}{66.0} = 0.240$$

$$S = \frac{I_L h^2}{I_h L^2} = \frac{16}{6.75} \times \left(\frac{24}{24}\right)^2 = 2.37$$

$$T = \frac{h(h + 2LQ')(c - b)(L^2 + 6hLQ + 2bc)}{L^2[4Sh(h + 2LQ') + (2h + LQ')(L + 6hQ)]} = 4.37 \text{ ft}$$

$$U = \frac{3(c - b)(L + 6hQ)Q'}{4Sh(h + 2LQ') + (2h + LQ')(L + 6hQ)} = 0.0838$$

By substituting these values into Eq. (10a) to (10f), the final reactions at the supports are obtained as follows: $M_{xa} = -94.5$ ft-kips, $M_{ya} = +4.7$ ft-kips, $R_{za} = +3.07$ kips, $M_{xd} = -75.6$ ft-kips, $M_{yd} = -28.5$ ft-kips, and $R_{zd} = +1.93$ kips.

It can be seen that these moments and forces are by no means small and should not be ignored. One may, of course, question whether the specified longitudinal forces do actually exist or not, but certainly will not doubt their effects on the analysis once the provisions in the standard specifications are accepted. If more slender members are introduced in the frame, either for esthetic or economical reasons, the effects become even more significant.

CONCLUSION

Although only the general solution of frames with prismatic members has been presented here, the method may be extended to members with variable cross sections provided that the angle of twist and the torsional stiffness of such members can be determined. The classical solutions of such quantities have been developed for solids of revolution having variable diameters, such as cone, ellipsoid, paraboloid, and hyperboloid (Reference 5, p. 302). For the types of variable sections prevalent for highway bridge piers, such as straight or parabolic haunches, no such solutions are available. To extend the method to frames with nonprismatic members, one must rely, therefore, on further assumptions and approximations. The other alternative is to determine the torsional properties of the members of variable cross sections by test of models.

In spite of these limitations, the method presented will be applicable to a large number of piers designed for highway bridges. It is hoped that more rational analysis will lead to designs of greater economy and safety.

ACKNOWLEDGMENT

Acknowledgment is made to Charles H. Clarahan, Jr., chief designer, Howard, Needles, Tammen and Bergendoff, Consulting Engineers, New York, for suggesting the problem on which this paper is based.

REFERENCES

1. "Standard Specifications for Highway Bridges," American Association of State Highway Officials, 7th Edition, 1957, p. 17, Article 1.2.13.

2. Baron, F., and Michalos, J. P., "Laterally Loaded Plane Structures and Structures Curved in Space," *Transactions*, ASCE, V. 117, 1952, pp. 279-316.

3. Cross, H., and Morgan, N. D., *Continuous Frames of Reinforced Concrete*, John Wiley & Sons, Inc., New York, 1932, pp. 81-117.

4. Peabody, D., *The Design of Reinforced Concrete Structures*, John Wiley & Sons, Inc., New York, 1946, pp. 414-420.

5. Timoshenko, S., and Goodier, J. N., *Theory of Elasticity*, McGraw-Hill Book Co., Inc., New York, 2nd Edition, 1951, p. 263.

Received by the Institute Apr. 17, 1958. Title No. 55-55 is a part of copyrighted Journal of the American Concrete Institute, V. 30, No. 8, Feb. 1959 (Proceedings V. 55). Separate prints are available at 50 cents.

American Concrete Institute, P. O. Box 4754, Redford Station, Detroit 19, Mich.

Discussion of this paper should reach ACI headquarters in triplicate by May 1, 1959, for publication in the Part 2, September 1959 JOURNAL.

Title No. 55-56

AGGREGATES FROM ALABAMA, ILLINOIS, AND KANSAS were studied in concretes made with cements having 0.23 to 1.4 percent alkali and 2.1 to 4.9 percent MgO. Studies extended over a period of 105 months. It is concluded that some of the expansion and cracking of concrete made with some sand-gravel aggregates from Kansas may be caused by a combination of alkali-aggregate reaction plus the hydration of periclase. The alkali-aggregate reaction is believed responsible for starting a mechanism which permits the periclase to cause excessive expansion. The periclase content of the cement does not appear to influence cracking obtained with the Alabama aggregate.

Expansion and Cracking

studied in relation to aggregate and the magnesia and alkali content of cement

By W. C. HANSEN

■ THIS INVESTIGATION WAS UNDERTAKEN in an effort to explain the expansion and cracking that occurs in concrete made with certain aggregates which has not appeared to be explained satisfactorily on the basis of the so-called alkali-aggregate reaction. The investigation was designed to study the influence of the magnesia and alkali contents of cements on the expansion and cracking of concretes made with two aggregates[1,2] which have poor service records in some structures, and of concrete made with one aggregate which has a good service record.

MATERIALS

Aggregates

The three aggregates were as follows:

1. Sand and gravel from a pit near Montgomery, Ala. (poor service record)
2. Sand-gravel from the Republican River near St. Francis, Kan. (poor service record)
3. Sand and gravel from Elgin, Ill. (good service record)

In certain states, such as Kansas, the deposits of sand and gravel contain little material retained on the No. 4 sieve. These are referred to as sand-gravel aggregates in contrast to the normal sand and gravel aggregates found in most states.

Cements

All cements were made in one plant. Raw materials were selected to give a cement with about 0.25 percent alkali by weight, expressed as Na_2O. (In this paper, the term alkali content always means percent Na_2O plus 0.658 percent K_2O.) By selecting limestone from various locations in the quarry, it was possible to vary the MgO content of the cement in the range of 2.0 to 5.0 percent. Three basic kiln feeds were used, each having an alkali content which would give about 0.25 percent Na_2O in the cement. The MgO contents of the kiln feeds were varied so as to give about 2.0, 3.5 or 5.0 percent MgO in the finished cement. Soda ash was added to these basic mixes to give cements with about 0.25, 0.70 and 1.1 percent alkali.

This gave a set of three cements with about 0.25 percent alkali and MgO contents of about 2.0, 3.5 and 4.5 percent; another set of three cements had alkali content of about 0.7 percent and MgO contents of about 2.0, 3.5, and 4.5 percent; a third set of three cements had about 1.1 percent alkali and MgO contents of about 2.0, 3.5 and 4.5 percent. A fourth set of three cements was made with a MgO content of about 4.5 percent and alkali contents of about 0.25, 0.70, and 1.1 percent in which the Fe_2O_3, which was about 2.5 percent in the other cements, was raised to about 3.5 percent.

Since the object of the study was to limit the variables in the cements as far as possible to the MgO and Na_2O content, an effort was made to hold the other components as constant as possible. The MgO and alkali contents of these cements are shown in Table 1. It was necessary, of course, to adjust the other oxides as the MgO and Na_2O contents were increased. Variation in the principal oxides for the three MgO levels is shown in Table 2.

The plant in which these cements were made was not equipped for quenching the clinker. However, it was possible to blow air on it as it flowed through a pipe from the kiln to storage. In this study, one portion of each clinker was discharged from the kiln without being subjected to a blast of air and another portion was subjected to a blast of air. It was hoped that the latter would increase the glass phase and lower the periclase content of the clinker. It was impossible from an examination with a petrographic microscope to detect any significant difference between the slowly cooled and rapidly cooled clinker. However, each type of clinker was ground into cement and used in making the specimens described below. The *U* following the cement number represents slowly cooled or unquenched and *Q* represents rapidly cooled clinker. All cements were ground in a cold mill to specific surfaces of 1850 ± 40 sq cm per g and all met the ASTM specifications for Type I cement.

FIELD TEST PROGRAM

Test specimens

Each cement was used to make a 36 x 36 x 6-in. slab and four 3 x 3 x 11¼-in. prisms with each of the three aggregates. The slab was made in the field with its top surface level with the surface of the soil. The four prisms were made from the same batch of concrete as that used for the slab and were cured

W. C. HANSEN, director research laboratories, Universal Atlas Cement Division, United States Steel Corp., received his Ph.D. in physical chemistry from Columbia University. He conducted research on the constitution of portland cement at the National Bureau of Standards, Washington, D. C., and on portland cement concrete while employed by the Portland Cement Association, Chicago, and has had papers published in these fields. He has been associated with the Universal Atlas Cement Division since 1945; his membership in ACI also dates from that year.

1 day under wet burlap in the mold. They were then removed from the molds and placed in the laboratory fog room for 2 days. Initial length measurements were then made and two prisms of a set were buried horizontally in the soil in the field with the top surface as cast flush with the level of the soil. The other two prisms of the set were buried vertically in the soil to about half their length. The results for the latter prisms are not reported here because they were similar to those of the specimens which were stored horizontally.

Concrete mixes

The Alabama and Illinois aggregates were used to make specimens of normal sand and gravel air-entrained concretes with a cement content of about 6.0 sacks per cu yd, water-cement ratios between about 4.8 and 5.2 gal. per sack of cement, and air contents between about 3.5 and 5.0 percent. The air was entrained by adding neutralized Vinsol resin at the mixer.

In the set of specimens made with the Kansas sand-gravel aggregate, the concretes had cement contents between 6.5 and 6.9 sacks per cu yd, water-cement ratios between 4.4 and 4.9 gal. per sack of cement, and air contents between 7.2 and 9.7 percent.

A set of specimens was made with Illinois aggregate graded to the gradation of the Kansas sand-gravel aggregate. The concretes had cement contents between 6.5 and 6.7 sacks per cu yd, water-cement ratios between 4.9 and 5.3 gal. per sack of cement, and air contents between 7.8 and 10.5 percent.

Examination and measurement

The surfaces of the slabs are examined and rated each year in April and October for extent of crazing and cracking. The prisms are taken to the laboratory at these times and stored in the fog room for several days to permit them to become fairly well saturated with water and to attain a uniform temperature. They are then measured for changes in length and weight. Expansion of the prisms stored horizontally for the concretes made with Illinois sand-gravel, Kansas sand-gravel, and Alabama sand and gravel aggregates is given in Table 1 for several periods up to 105 months. The expansions obtained with the specimens of the Illinois sand and gravel concrete were nearly the same as those reported in Table 1 for the Illinois and Alabama aggregates.

TABLE 1—EXPANSION of 3 x 3 x 11¼-IN. PRISMS STORED HORIZONTALLY IN THE FIELD

No.	Cement MgO, percent	Cement Na_2O, percent	Expansion, percent, for Illinois sand-gravel aggregate concrete, stored indicated number of months				Expansion, percent, for Kansas sand-gravel aggregate concrete, stored indicated number of months				Expansion, percent, for Alabama sand-gravel aggregate concrete, stored indicated number of months			
			12	24	68	105	12	24	68	105	12	24	68	105
10	2.1	0.23	0.027	0.045	0.169	0.251	0.029	0.051	0.175	0.264	0.026	0.043	0.164	0.248
10	2.1	0.25	0.029	0.046	0.172	0.253	0.032	0.055	0.186	0.291	0.024	0.040	0.157	0.245
20	3.7	0.35	0.032	0.043	0.170	0.248	0.035	0.071	0.313	0.486	0.023	0.039	0.161	0.238
20	3.5	0.28	0.024	0.042	0.167	0.247	0.029	0.077	0.344	0.504	0.021	0.041	0.163	0.244
30	4.9	0.24	0.036	0.059	0.190	0.270	0.033	0.100	0.477	0.846	0.025	0.049	0.184	0.288
30	4.2	0.39	0.029	0.050	0.180	0.267	0.033	0.077	0.370	0.671	0.028	0.050	0.187	0.281
40	2.2	0.79	0.034	0.056	0.177	0.262	0.042	0.087	0.455	0.666	0.030	0.045	0.171	0.252
40	2.4	0.76	0.032	0.050	0.178	0.261	0.043	0.092	0.399	0.748	0.022	0.040	0.164	0.244
50	3.6	0.79	0.028	0.047	0.177	0.254	0.040	0.107	0.505	0.783	0.023	0.042	0.165	0.245
50	3.6	0.71	0.017	0.040	0.166	0.240	0.038	0.069	0.269	0.405	0.031	0.050	0.174	0.259
60	4.0	0.71	0.029	0.048	0.178	0.263	0.038	0.091	0.535	0.730	0.026	0.047	0.174	0.257
60	4.4	0.97	0.030	0.049	0.171	0.257	0.046	0.123	0.661	0.845	0.034	0.055	0.186	0.271
70	2.1	1.36	0.031	0.049	0.176	0.253	0.042	0.094	0.419	0.611	0.029	0.048	0.172	0.248
70	2.3	1.02	0.031	0.054	0.178	0.261	0.050	0.231	0.621	0.847	0.027	0.046	0.177	0.263
80	3.0	1.11	0.032	0.052	0.181	0.259	0.027	0.129	0.560	0.704	0.028	0.046	0.166	0.244
80	3.0	1.09	0.033	0.054	0.181	0.261	0.034	0.108	0.469	0.595	0.039	0.054	0.174	0.255
90	4.5	1.15	0.034	0.056	0.183	0.258	0.056	0.171	0.629	0.824	0.027	0.053	0.181	0.265
90	4.2	0.92	0.038	0.061	0.190	0.268	0.051	0.117	0.577	0.747	0.037	0.055	0.186	0.269
100	4.6	0.25	0.030	0.051	0.180	0.256	0.034	0.107	0.453	0.673	0.030	0.050	0.178	0.259
100	4.6	0.27	0.028	0.042	0.169	0.240	0.009	0.057	0.390	0.604	0.026	0.044	0.178	0.263
110	4.7	0.76	0.031	0.055	0.196	0.259	0.036	0.125	0.582	0.781	0.029	0.049	0.181	0.267
110	4.5	0.69	0.031	0.050	0.180	0.260	0.036	0.115	0.540	0.721	0.031	0.049	0.176	0.257
120	4.9	1.19	0.035	0.061	0.192	0.272	0.028	0.222	0.616	0.785	0.031	0.049	0.175	0.257
120	4.3	1.13	0.033	0.056	0.180	0.258	0.039	0.147	0.526	0.695	0.036	0.052	0.167	0.254
Average			0.031	0.051	0.178	0.257	0.038	0.109	0.465	0.659	0.028	0.047	0.173	0.257

TABLE 2—VARIATION IN PRINCIPAL OXIDES FOR DIFFERENT MAGNESIA CONTENTS OF CEMENT

Oxide	2.0 percent MgO	3.5 percent MgO	4.5 percent MgO	4.5 percent MgO
SiO_2, percent	21.2 to 20.9	22.5 to 21.3	22.1 to 21.2	21.2 to 20.3
Al_2O_3, percent	5.8 to 5.3	4.8 to 4.5	5.2 to 4.5	5.0 to 4.8
Fe_2O_3, percent	2.4 to 2.2	2.5 to 2.4	2.3 to 2.2	3.6 to 3.1
CaO, percent	65.4 to 63.3	63.0 to 61.9	63.2 to 60.7	63.0 to 60.7

Test series expanded

The slabs made with the Kansas aggregate and cements with alkali contents above 0.7 percent crazed and cracked (see Table 4) fairly extensively within the first 2 years. None of the cements used in this study had alkali contents between 0.39 and 0.71 percent and none of the slabs made with the cements having 0.39 percent or less alkali were crazed at the end of 2 years. Hence, it was decided to expand the project and explore the range between 0.4 and 0.7 percent alkali. The expansion of the prisms stored horizontally seemed to be a good criterion of the behaviors of the concretes. Accordingly, blends were made of the cements to give alkali contents of about 0.3, 0.4, 0.5, 0.6 and 0.8 percent for each of the MgO contents. Two 3 x 3 x 11¼-in. prisms were made from each of these cements and each of the Illinois and Kansas sand-gravel aggregates. These prisms were stored horizontally in the field. The MgO and Na_2O contents of these cements and expansion of the prisms up to 72 months are given in Table 3.

DISCUSSION OF RESULTS

Cracking of the slabs generally started by the surfaces showing a fine map cracking which has been called crazing. This was followed by the fine crazing checks developing into distinct cracks at the edges of the slab and then by an enlargement of the cracks and an extension over the entire surface.* Table 4 gives the ratings up to 105 months for the surfaces of the slabs made with Alabama sand and gravel concrete and the Kansas sand-gravel concrete. None of the slabs made with the Illinois aggregates showed any crazing or cracking.

Kansas aggregate

With the exceptions of Cements 5Q, 5U, and 11U, all of the slabs made with cements containing more than 0.7 percent alkali were cracked at 42 months. Those made with Cements 5Q, 5U, and 11U were cracked at 78 months. The eight slabs made with the low alkali cements (0.23 to 0.39 percent) showed no cracking for 54 months. At 105 months, four of them showed no cracking and four showed cracking along the edges. The last four are those made from the cements having between 4.2 and 4.9 percent MgO.

The expansions at several periods of the prisms made with Illinois sand-gravel concrete, Kansas sand-gravel concrete, and Alabama sand and gravel

*The cracking of these slabs resembled that shown in Fig. 1 of Reference 2.

TABLE 3—EXPANSION of 3 x 3 x 11¼-IN. PRISMS STORED HORIZONTALLY IN THE FIELD

Cement			Expansion, percent, for concrete made with Illinois sand-gravel aggregate, stored indicated number of months					Expansion, percent, for concrete made with Kansas sand-gravel aggregate, stored indicated number of months				
No.	MgO, percent	Na_2O, percent	12	24	48	60	72	12	24	48	60	72
1Q	2.1	0.23	0.049	0.060	0.106	0.142	0.175	0.049	0.066	0.115	0.158	0.193
3Q	4.9	0.24	0.056	0.063	0.107	0.152	0.192	0.063	0.084	0.173	0.281	0.358
2U	3.5	0.28	0.039	0.050	0.095	0.138	0.172	0.066	0.089	0.136	0.184	0.225
5Q + 3 (2U)	3.7	0.41	0.050	0.063	0.111	0.157	0.186	0.061	0.094	0.259	0.375	0.461
4Q + 2 (1Q)	2.1	0.42	0.046	0.057	0.106	0.145	0.175	0.053	0.076	0.136	0.194	0.248
6Q + 10Q + 2Q	4.1	0.44	0.056	0.067	0.114	0.153	0.187	0.066	0.097	0.216	0.286	0.340
4Q + 1Q	2.2	0.51	0.040	0.051	0.095	0.138	0.167	0.058	0.075	0.140	0.213	0.289
4Q + 2U	2.9	0.54	0.045	0.055	0.102	0.143	0.173	0.069	0.095	0.209	0.331	0.440
5Q + 2U	3.6	0.54	0.046	0.061	0.109	0.148	0.182	0.073	0.119	0.338	0.462	0.545
10Q + 2 (11Q)	4.7	0.59	0.047	0.062	0.108	0.153	0.181	0.070	0.106	0.255	0.350	0.425
1Q + 2 (4Q)	2.3	0.60	0.042	0.055	0.101	0.142	0.172	0.057	0.073	0.125	0.179	0.219
2U + 2 (5Q)	3.6	0.62	0.048	0.064	0.106	0.150	0.179	0.070	0.111	0.312	0.445	0.533
11Q	4.7	0.76	0.050	0.066	0.111	0.155	0.181	0.067	0.114	0.243	0.317	0.376
4Q	2.2	0.79	0.043	0.054	0.097	0.138	0.171	0.061	0.079	0.172	0.250	0.311
5Q	3.6	0.79	0.050	0.060	0.108	0.148	0.179	0.067	0.108	0.311	0.421	0.493
Average			0.047	0.059	0.105	0.147	0.178	0.063	0.092	0.209	0.296	0.364

TABLE 4—RATINGS OF SURFACES OF 36 x 36 x 6-IN. CONCRETE SLABS

Cement			Slab made with Kansas sand-gravel concrete, exposed for indicated number of months						Slab made with Alabama sand and gravel concrete, exposed for indicated number of months						
No.	MgO, percent	Na_2O, percent	12	30	42	54	78	105	12	30	42	54	78	90	105
1Q	2.1	0.23	A	A	A	A	A	A	A	A	A	A	A	A	A
1U	2.2	0.25	A	A	A	A	A	A	A	A	A	A	A	A	A
2Q	3.7	0.35	A	A	A	A	A	A	A	A	A	A	A	A	A
2U	3.5	0.28	A	A	A	A	A	A	A	A	A	A	A	A	A
3Q	4.9	0.24	A	A	A	A	A	C	A	A	A	A	A	A	A
3U	4.2	0.39	A	A	A	A	A	C	A	A	A	A	A	A	A
10Q	4.6	0.25	A	A	A	A	C	C	A	A	A	A	A	A	A
10U	4.6	0.25	A	A	A	A	A	C	A	A	A	A	A	A	A
4Q	2.2	0.79	B	B	C	C	D	D	B	B	B	B	B	B	B
4U	2.4	0.76	A	A	C	C	D	D	A	A	A	A	A	A	A
5Q	3.6	0.79	A	A	A	A	D	D	B	B	B	B	B	B	B
5U	3.6	0.71	A	A	A	A	D	D	B	B	B	B	B	B	B
6Q	4.0	0.71	A	C	C	D	D	D	A	A	A	A	B	B	B
6U	4.4	0.97	A	C	D	D	D	D	B	B	B	B	B	B	B
11Q	4.7	0.76	A	C	D	D	D	D	B	B	B	B	B	B	B
11U	4.5	0.79	A	A	A	A	D	D	B	B	B	B	B	B	B
7Q	2.1	1.36	B	D	D	D	D	D	B	B	B	B	D	D	D
7U	2.3	1.02	B	C	C	C	D	D	B	B	B	B	B	B	C
8Q	3.0	1.11	A	A	C	D	D	D	A	A	A	A	A	A	A
8U	3.0	1.09	A	A	C	C	D	D	B	B	B	B	B	B	B
9Q	4.5	1.15	A	D	D	D	D	D	B	B	B	B	C	C	D
9U	4.2	0.92	C	D	D	D	D	D	B	B	B	B	B	C	C
12Q	4.9	1.19	A	C	D	D	D	D	B	B	B	B	B	B	D
12U	4.3	1.13	A	B	C	D	D	D	B	B	B	B	B	B	C

A = No crazing
B = Extensive crazing
C = Extensive crazing and edges mottled and cracked
D = Entire surface mottled and cracked

TABLE 5—COMPARISON OF CEMENTS WHICH PRODUCED LEAST CRACKING WITH KANSAS AGGREGATES

	Cement							
	1Q	1U	2U	2Q	3U	10Q	10U	3Q
Expansion at 105 months, percent	0.264	0.291	0.504	0.486	0.671	0.673	0.604	0.846
Alkali content, percent	0.23	0.25	0.28	0.35	0.39	0.25	0.27	0.24
MgO content, percent	2.1	2.1	3.5	3.7	4.2	4.6	4.6	4.9

concrete are given in Table 1. The average expansions for the 48 prisms made with the 24 cements are as follows:

Aggregate	12 months	24 months	68 months	105 months
Illinois	0.031	0.051	0.178	0.257
Alabama	0.028	0.047	0.173	0.257
Kansas	0.038	0.106	0.465	0.659

These results show no differences between the cements when used with the Illinois and the Alabama aggregates. At the 24-month and later periods, the expansions for the prisms made with the Kansas aggregate were much greater than those for the prisms made with the other aggregates; generally, the amount of expansion appeared to be a function of the alkali content of the cement. Thus, it appears that expansion in these prisms and the cracking of the slabs are associated with an alkali-aggregate reaction.

In the group of cements with alkali contents greater than 0.7 percent, Cements 5Q, 5U, and 11U gave slabs which were the last to develop cracks. However, on the basis of the expansions in the prisms, Cements 5Q and 11U do not appear to be better than the others in this group but Cement 5U did show the lowest expansion for this group.

In the group of cements with alkali contents between 0.23 and 0.39 percent, the prisms for Cements 1Q and 1U are the only ones that show expansions at 105 months of less than 0.4 percent. They showed 0.264 and 0.291 percent expansion, respectively, not appreciably different from the expansions shown for all of the cements with the other two aggregates.

The slabs made with Cements 1Q, 1U, 2Q, and 2U are the only ones that did not show cracking at 105 months. However, the prisms made with Cements 2Q and 2U show 0.486 and 0.504 percent expansion, respectively.

From the standpoint of the cracking of the slabs, the eight cements with less than 0.4 percent alkali have given what might be considered an almost perfect service record for 105 months. However, the slabs made with four cements (3Q, 3U, 10Q, and 10U) with MgO between 4.2 and 4.9 percent show some cracking at this period.

These eight cements are compared from the standpoint of prism expansion and alkali and MgO content in Table 5. There is no evidence from either these or the data for the other cements that the type of cooling affected cement behavior. This was expected since it was impossible from microscopic examinations to observe any effect of the rapid cooling on either glass or periclase content.

Effect of magnesia and alkali

The data for these eight cements suggest that the MgO content influences expansion of the prisms. This will be pursued further with the data of Table 3. These data give the expansions up to 72 months of prisms made with blends of cements. The blends had alkali contents of approximately 0.2, 0.4, 0.5, 0.6, and 0.8 percent with each of the three MgO contents of approximately 2.0, 3.5, and 4.5 percent. The expansions at 72 months for the Illinois sand-gravel aggregate concrete ranged between 0.171 and 0.192 percent, with an average of 0.178 percent. Those for the Kansas sand-gravel aggregate concrete ranged between 0.193 and 0.545 percent, with an average of 0.364 percent.

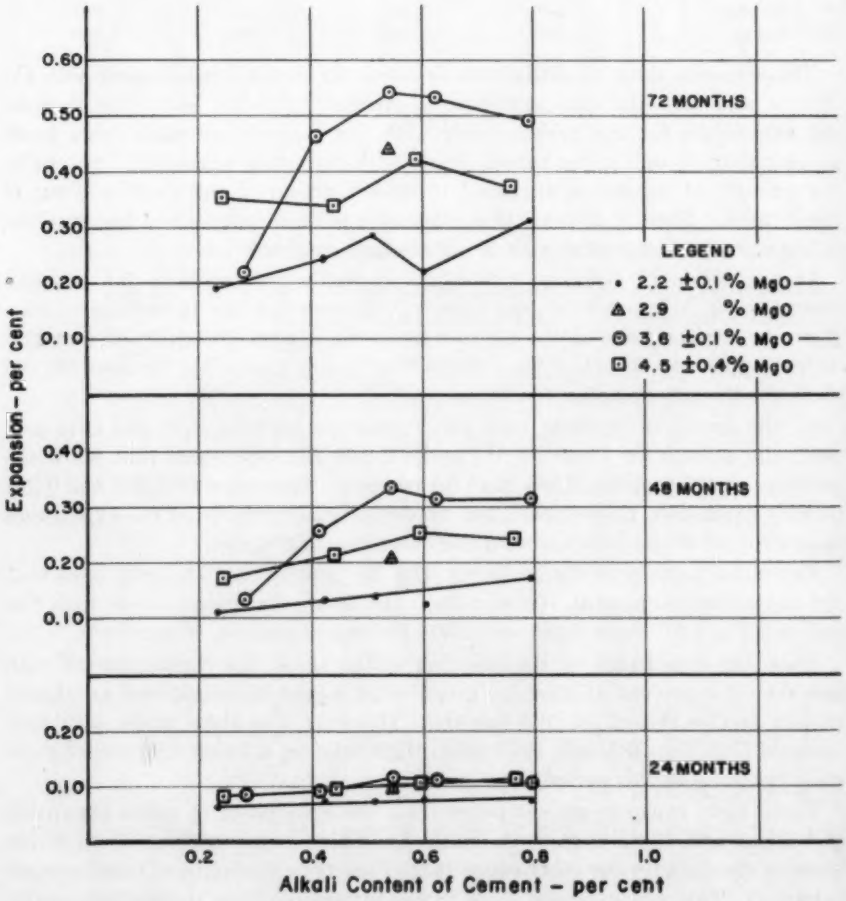


Fig. 1—Expansion of prisms made with Kansas aggregate, plotted against alkali content of the cement

The 24, 48, and 72-month expansions of Kansas aggregate concrete are plotted against the alkali contents of the cements in Fig. 1. The plot of the 24-month data shows a trend toward increased expansion with increases in the alkali and MgO content of the cement.

The plots of the 48 and 72-month data show a clearly defined trend of increasing expansion with increasing alkali content of the cement. However, these plots show that the MgO content of the cement contributes markedly to the expansion. In all but one case, the prisms made from cements with 2.9 to 3.7 percent MgO expanded more than those made from cements with MgO between 4.1 and 4.9 percent. This seems to be the opposite of what one would expect, but no explanation is apparent.

MECHANISMS OF EXPANSIVE REACTIONS

A number of investigators have expressed the opinion that some reaction (usually referred to as a cement-aggregate reaction) other than alkali-aggregate reaction is responsible for the cracking of concrete made with certain sand-gravel aggregates. This opinion is based on the observation that there appears to be no satisfactory correlation between the alkali content of cement and the expansion and cracking obtained in either laboratory specimens or field structures. However, a number of investigators[3] have shown from petrographic examinations that some of these sand-gravel aggregates contain materials that will react with alkalies in concrete and might be responsible for much of the expansion and cracking obtained when cements of relatively high alkali content are used.

The data plotted in Fig. 1 support the conclusion that some reaction other than the alkali-aggregate reaction is involved in the expansions of these prisms made with the Kansas sand-gravel aggregate. However, it appears that the alkali-aggregate reaction is responsible for *starting* a mechanism which permits the MgO to cause excessive expansion. This conclusion is based on the following:

1. The expansions up to 105 months for concretes made with Illinois sand-gravel aggregate and with Alabama and Illinois sand and gravel aggregates are essentially alike regardless of either the alkali or the MgO content of the cements.

   (a) This seems definitely to show that the size and gradation of the aggregate is not responsible for the expansions obtained with sand-gravel aggregate.

   (b) It also seems to indicate that the MgO content of the cements dealt with in this study will not cause excessive expansion without an assist from some factor that is abnormal to the type of concrete produced with the aggregates from Illinois and Alabama.

2. It is well known that MgO in the form of periclase will react with water in concrete and cause expansion and cracking of the concrete. Since the MgO in the concretes made with Illinois and Alabama aggregates appears not to be causing excessive expansions, it seems that the MgO in the Kansas aggregate concrete must have greater access to water than does the MgO in the other concretes. The permeabilities of the three types of concrete, it seems, should not have been greatly different because their water-cement ratios were similar. Hence, the behavior of the concrete

made with Kansas aggregate does not appear explainable on the basis of the permeability of the original hardened concrete to water.

The fundamental mechanism of the alkali-aggregate reaction appears to be associated with the formation of expanded units in the cement mortar. These units exert pressure and cause expansion when the concrete is moist but they probably rarely cause cracking until the concrete dries because concrete has a high compressive strength but a low tensile strength. These expanded units in concrete made with a low-alkali cement may not be sufficient to produce much expansion but they may exert sufficient restraint during drying to produce minute cracks in the cement paste. Such cracks could permit water to migrate freely to the grains of periclase when the concrete is wetted.

Accordingly, the mechanism of expansion and cracking involved with reactive sand-gravel aggregates appears to be as follows:

1. Reactions between particles of aggregate and alkalies from the cement enlarge these reactive particles.

2. The enlarged particles tend to expand the structure, but with low-alkali cements this expansion may be small.

3. When the structure dries, the expanded particles restrain the shrinkage of the cement paste and produce minute cracks in it.

4. These cracks in the cement paste increase the permeability of the paste to water and permit water to contact grains of periclase when the concrete is wetted.

5. The hydration of the grains of periclase causes expansion and, on drying of the concrete, these expanded grains restrain the shrinkage and cause additional cracking.

In this mechanism, the only cement-aggregate reaction is the alkali-aggregate reaction. There is no reaction between the periclase and the aggregate.

Behavior of concrete made with sand-gravel aggregate has been studied by a number of testing procedures. The investigators have not reached clear-cut conclusions except that the expansions are not explained in terms of only the alkali contents of the cements. Conrow[4] suggested that the expansions are related to the calcium hydroxide content of the mortar. However, results of a cooperative study[5] by six laboratories led to the conclusion that other phenomena associated with the hydration of portland cement in addition to the release of $Ca(OH)_2$ by hydrolysis of the cement minerals were involved in the expansions in this type of concrete.

The work reported here (which was begun in 1948) was not designed to cover variables in the compositions of the cement other than the MgO and Na_2O content. However, as pointed out earlier, the CaO content had to vary with variations in the MgO and Na_2O content. The cements low in MgO which had the highest CaO and calculated $3CaO \cdot SiO_2$ contents showed the lowest expansions. Hence, the results of this study do not offer any support to the suggestion that the $Ca(OH)_2$ is a factor in the expansions of the sand-gravel aggregate concrete.

Alabama aggregate

There is slight evidence from the crazing on the surfaces of the slabs (Table 4) that this aggregate is reactive toward alkalies because the crazing occurs only on the slabs in which the alkali content of the cements exceeded 0.7 percent. Also, there are a few cracks in some of the slabs made with the cements of very high alkali content. However, the prisms made with this aggregate do not show greater expansions than those made with the Illinois aggregate.

These results suggest that this aggregate contains some pieces of reactive material* which are so distributed as to be unable to produce much of an overall expansion in the slabs or prisms but can exercise sufficient restraint to cause some cracking during drying. The amount of this type of cracking seems to be insufficient to increase the permeability of the paste to water and permit water to attack the grains of periclase.

In the slabs made with this aggregate, the only noticeable cracking occurred with cements that contained over 0.9 percent alkali. Hence, the results of this study indicate that this aggregate could be used safely with cements of low and moderate alkali content and with 4.7 percent or less MgO.

CONCLUSIONS

It is realized that the results obtained for a sample of natural aggregate apply only to that particular sample. However, the sand-gravel aggregate from the Republican River in Kansas seems to have a poorer service record than most of the sand-gravel aggregates that have been used. Hence, it seems likely that cements that would give satisfactory service records with this aggregate would give as good or better service records with similar aggregates from other sources. On this basis, it appears that the sand-gravel aggregates of Kansas, Nebraska and Iowa could be used safely with cements having alkali content of not more than about 0.6 percent and MgO content of not more than about 2.5 percent.

One might question the selection of the maximum values of 0.6 percent for alkalies and 2.5 percent for MgO when it is seen from Fig. 1 that, at 72 months, prisms with such cements show between 0.2 and 0.3 percent expansion. It seems that the reactions in these small prisms must be much more advanced at any given time than they would be in a relatively large concrete structure. For example, the slabs made with Cements 2Q and 2U showed no crazing nor cracking at 105 months but the prisms had expanded 0.486 and 0.504 percent, respectively. Hence, it seems safe to conclude that concrete structures in service will not expand to the degree that small prisms will when completely embedded in soil.

The service records of concrete in Georgia and Alabama indicate that cracking is much less severe with cements of moderate and low alkali content than with high alkali cements. The results of this study indicate that this should

*Microscopic examinations of pieces of the slabs showed deposits of white gels.

be the case and that the MgO content of the cement is not a factor in the performance of this Alabama aggregate.

ACKNOWLEDGMENT

The author acknowledges the help of many of his colleagues who supervised and carried out the experimental work of this investigation.

REFERENCES

1. Hester, J. A., and Smith, O. F., "The Alkali-Aggregate Phase of Chemical Reactivity in Concrete. Part II—Deleterious Reactions Observed in Field Concrete Structures," *Research Report*, Bureau of Materials and Tests, Alabama State Highway Department, July 1956.

2. Peyton, R. L., Stingley, W. M., and Meyer, R. C., "Effect of Pozzolans Added to Sand-Gravel Concrete Pavement," *Proceedings*, Highway Research Board, V. 34, Jan. 1955, p. 302.

3. McConnell, Duncan, Mielenz, Richard, Holland, William Y., and Greene, Kenneth T., "Cement-Aggregate Reaction in Concrete," ACI JOURNAL, V. 19, No. 2, Oct. 1947 (*Proceedings* V. 44), pp. 93-128.

4. Conrow, A. D., "Studies of Abnormal Expansion of Portland Cement Concrete," *Proceedings*, ASTM, V. 52, 1952, pp. 1205-1223.

5. Report of ASTM Committee C-9 on Concrete and Concrete Aggregates, *Proceedings*, ASTM, V. 54, 1954, pp. 347-373.

Received by the Institute Aug. 18, 1958. Title No. 55-56 is a part of copyrighted Journal of the American Concrete Institute, V. 30, No. 8, Feb. 1959 (Proceedings V. 55). Separate prints are available at 50 cents.

American Concrete Institute, P. O. Box 4754, Redford Station, Detroit 19, Mich.

Discussion of this paper should reach ACI headquarters in triplicate by May 1, 1959, for publication in the Part 2, September 1959 JOURNAL.

Title No. 55-57

Presents requirements for materials, methods, and workmanship in constructing or resurfacing floors, platforms, and aprons subject to heavy traffic or to severe use from the handling of heavy materials. Various methods of treating wearing surfaces made of concrete are discussed.

Wear-Resistant concrete construction

By SHU-T'IEN LI

WEAR-RESISTANT qualities of concrete constitute an important and necessary consideration in constructing or resurfacing heavy-duty concrete floors; factory working areas; passenger and freight platforms at railway, bus, and truck depots; aprons and floors at transit sheds of docks, wharves, piers, and quays. Under all these circumstances, the construction must withstand the mechanical wear that is constantly imposed on the surface course.

A complete answer to floor construction should encompass (a) proper construction of base slab, and (b) proper construction of surface or wearing course. This two-course construction is indispensable, because:

1. The higher quality materials and workmanship required for the surface can be limited to the thinner wearing course, thereby making construction more economical.
2. This scheme provides the easiest and most convenient renewal when it becomes necessary.

To confine the discussion to a reasonable length, it is assumed that the base slab has been properly designed in all respects and constructed with suitable materials and appropriate workmanship to adapt itself to the underlying foundation or supporting conditions, and to be compatible with its overlying wearing course.

CONSTRUCTION OF WEARING COURSE

Thickness and slope

A study of the best contemporary practice in various countries with respect to thickness of the wearing course leads to the following recommendations:

1. Minimum of ¾ in. to a maximum of 1 in. thick if the wearing course is applied to a fresh concrete base the same day in which the base course is placed; preferably 1 in. thick if laid the next day; and 1½ in. thick if laid thereafter.
2. Minimum of 2 to 3 in. thick, depending on site and service conditions, if laid on a waterproof membrane.

The second condition occurs where the space under the base slab is exposed to wet conditions and moisture must be prevented from moving through it. The membrane should consist of bituminous asbestos felt (with or without a layer of acid-resistant asphalt, but preferably with one ply of saturated glass fabric), laid with broken joints in two coats to finish ½ in. thick. It should be bonded with bitumen to the body of the slab and designed as a liquid-tight receptacle that will shed seepage moisture into drains.

For convenience of construction and to provide required minimum drainage and cleansing slopes, it is recommended that the wearing course be:

1. Uniform in thickness.
2. Crowned with a gentle parabolic vertical curve, or with a minimum drainage slope of at least 1 in 60 for a smooth surface and 1 in 40 for a roughened surface in mild climate, and with a steeper minimum slope in localities where cycles of freezing and thawing occur.
3. Sloped transverse to the general direction of traffic for drainage.
4. Free from depressions or pockets that would retain liquid.

Preparation of base slab

The wearing course is supported by, will be affected by, and should be bonded to the base slab, hence the latter should be properly prepared. When the wearing course is to be placed the same day as the base slab, the surface of the base slab should be finished reasonably true, struck off at a surface profile parallel to that of the wearing course, and lowered by the thickness of the wearing course, so that the finished surface of the wearing course will be at the designed grade.

When the wearing course is to be placed sometime after the base slab, in addition to the requirements mentioned above, the surface of the base slab should be further prepared as follows. Before the base slab has fully hardened,

Long-time ACI member SHU-T'IEN LI has a varied background in concrete design and construction in this country and in China. Most of his work has been in the fields of structural and hydraulic engineering. He has served on the faculties of several engineering colleges in China and was Visiting Professor of Civil Engineering at Rutgers University in 1953-54. Dr. Li is currently in consulting practice in Mobile, Ala.

and after its condition permits, all dirt, laitance, and loose aggregate should be removed with a wire broom leaving the course aggregate slightly exposed; or after it has hardened, its surface should be prepared for bond by chipping, and all dirt, laitance, chipped mortar, and aggregate removed. Just prior to placing the wearing course, the base slab should be thoroughly scrubbed.

Essentials for durable wearing course

To insure wear-resistant qualities, the concrete must be hard, durable, and dense. Such concrete will "ring like an anvil" when struck with a hammer. To obtain sufficient wear-resistance, it is necessary to carefully consider:

1. Selection of materials.
2. Details of mix proportioning.
3. Manufacture and compaction of the concrete to give maximum density.
4. Effective curing.
5. Effective surface treatment.

Maximum density implies minimum porosity and permeability. Strong, tough, resilient concrete will suffer least from cracks. Effective curing and surface treatment will increase abrasion resistance and postpone the exposure of internal pores. This reduction of pores and cracks will retard the possible penetration of any acidifiable substance that will attack portland cement concrete and cause deterioration of the constituents of the hydrated cement. Thus, good concrete is not only capable of withstanding mechanical wear from without, but also eliminates deterioration from within.

There are many proprietary hardeners and dustproofers available. Each will serve its purpose to a certain extent under normal conditions, each will increase the serviceability of a good concrete, but none is a substitute for good concrete. However, an already good concrete may always be advantageously supplemented by surface treatment. Metal grids may be used to minimize local effects of abrasion, but unequal wear of the metal and concrete surfaces produces an uneven surface. A well laid concrete surface has a good resistance to abrasion, is easily constructed and cleaned, and can give satisfactory service. Durable concrete surfaces can be achieved by using:

1. Relatively rich mix with standard quality cement, proportioned for maximum density with sound, well graded aggregate, carefully weighed and thoroughly mixed with minimum water for workability.
2. Thorough and uniform consolidation with the aid of a power compactor weighing 250 lb or more, or a combined heavy power vibrating screed and compactor.
3. Adequate curing to ensure maximum hydration of cement.
4. Watertight construction joints.

Ingredients of surfacing concrete

Ingredients should comply with the requirements of their respective standard specifications and, in addition, the following considerations and stipulations are essential.

Water—Water is as important as any other constituent in concrete. Its required qualities are often neglected. However, the need for good quality

water can never be overemphasized. It should be clear and free from injurious amounts of oil, acid, alkali, organic matter, or other deleterious substances. In case of dubious quality through macroscopic examination, it should be analyzed and, if necessary, given proper treatment before use.

Cement—(a) In general, any of the portland cements defined in ASTM standards may be selected for a given construction depending on desired physical and chemical properties, and availability. However, Type II cement may usually be eliminated from consideration. Type IV cement is a little less vulnerable to chemical attack than Type I and Type III. Types IV and V should be used only where absolutely necessary, because they are not usually carried in stock. Type III cement can be put into service at an early age, since it hardens rapidly and requires only 1-day curing in moist air. (b) As cement can deteriorate rapidly in storage, it must conform to the requirements of standard specifications at the time of use. (c) The use of any high-alumina cement should be accompanied by slightly different treatment as set forth later. High-alumina cement concrete should not be used under continuously warm, damp conditions, or where there are alkaline hazards. (d) It is not advisable to use more than one type of cement on a given job, at least at the same time. The contamination of one type of cement with another, either directly or via equipment, should always be avoided.

Aggregates—Aggregate particles should be angular, but not flaky. No rounded aggregate should be used, as they cause slipperiness when exposed by wear. Both coarse and fine aggregate should be well graded for maximum density from the locally available processed aggregates by trial and tests, and they should further meet the following requirements. (a) Fine aggregate should consist of clean, hard sand or crushed stone screenings free from dust, clay, loam, or vegetable matter. All fine aggregate should be graded from coarse to fine with more than 95 percent passing the No. 4 sieve and less than 5 percent passing the No. 100 sieve. (b) Coarse aggregate should consist of clean, hard crushed stone such as basalt and traprock, granite, quartz, or diorite. All coarse aggregate must pass the $\frac{1}{2}$-in. sieve, with more than 90 percent passing the $\frac{3}{8}$-in. sieve, and less than 5 percent passing the No. 8 sieve.

Water-cement ratio and proportioning

The concrete should be of the driest consistency possible to work with a sawing motion of the strike-off board or straightedge. The lowest water content compatible with thorough compaction can be achieved as follows:

1. Water/cement ratio selected to ensure the required minimum compressive strength, or degree of durability, desired for a given service.
2. Aggregate graded such that when mixed with the cementitious paste will give the densest concrete.
3. Aggregate/cement ratio such that a workable mix can be fully compacted by a particular method of compaction.

Proportioning should be guided by experience and quantitatively determined from trial mixes.

Taylor[9] recommends that "The total quantity of water in the mix should be from 3½ gal. to not more than 4 gal. per cu ft of cement." Good practice has testified the soundness of this maximum relative water content in the mix. However, the Portland Cement Association[5] stipulates that "Not more than 5 gal. of mixing water, including the moisture in the aggregates, shall be used for each sack of portland cement in the mixture." This upper limit is too high for optimum results for any type of portland cement except high-early-strength cement.

Excess mixing water reduces the strength and durability of concrete by forming a great number of capillaries in escaping to the surface, and a weak surface film that is subject to crazing and dusting. Siliceous dust has a hardness value of 7 and acts as a grinding agent under truck wheels accelerating mechanical wear. The quantity of mixing water must, therefore, be carefully gaged, and all the free surface moisture of the component aggregates must be deducted from the prescribed amount.

For any locally available processed aggregate, the necessary slight variation in the mix to secure maximum density and required consistency should be determined by trial and standard laboratory tests. The specimen mix series for the wearing course may be planned around 1 part cement, 1.2 parts fine aggregate, and 2 parts ½- or ⅜-in. coarse aggregate, by weight. If the aggregate are comparatively coarse, the coarse material may be reduced, but its volume should preferably be not less than 1½ times the volume of the fine material.

Control of consistency

As concrete with a low water content requires more physical exertion to place and compact, contractors are inclined to add too much water, especially when power compactors are not available. A control should be exercised by the slump test. For the wearing course, a concrete with "zero" slump should be adhered to when finishing is performed with a power compactor. A slight slump, always kept well below 1 in., may be tolerated with caution if a power compactor is not available and the traffic on the floor is not extremely heavy. A no-slump mix should be made so that only an insignificant amount of moisture can be brought to the surface when a sample is squeezed in the hand.

Changes in consistency should be obtained by adjusting the proportions of fine and coarse aggregate within the limits previously cited, or by introducing an air-entraining or a wetting agent in percentages within the limits given below; but in no case should the amount of mixing water exceed 4 gal. per bag of normal portland cement.

Air-entraining or wetting agents

In the present state of the science and art of manufacturing wearing-course concrete, there is a new vista in adhering to the lowest possible water content and in improving the workability of mixes and the quality of concrete by an air-entraining or a wetting agent. Several proprietary materials of this nature are available. For best results, they should have a low content of free sulfate, and addition at the mixer should be in accordance with the recommendations

of the manufacturer. Within the limits of 3 to 6 percent, entrained air will decrease the permeability and increase the durability of the concrete. The total quantity of water in the mix, including that in the aggregates and in the air-entraining or wetting agent, may thus be reduced while maintaining a necessary given degree of workability. Concurrently, the fine aggregate may be reduced slightly by an amount equal to the net change in volume of air plus water so that the cement factor of the concrete is kept constant. Air-entraining agents are somewhat more effective than wetting agents in this respect, but wetting agents are capable of improving the dispersion and hydration of the cement and the quality of the concrete.

MIXING

Weighing

It is always preferable to measure the constituents of the mix by weight rather than by volume, using special weigh-batchers or adapting platform scales. Aggregates vary with materials used, and should be carefully weighed for best results. When the weight of fine aggregate is determined by sampling and actually measured by equivalent volume, a correction becomes necessary for bulking due to moisture content.

Corrections

Good practice dictates the use of full bags of cement per batch. Should it be necessary to use less than a bag per batch, appropriate allowance must be made for the increase in volume of cement due to aeration by disturbance.

To allow for the weight of free moisture in the aggregate, corrected batch weight is

$$W_b = \frac{W_d}{1-m}$$

where W_d is the dry weight required, m is the total free moisture content expressed as a decimal, and W_b is the corrected batch weight.

Total free moisture, m, consists of free surface moisture, m_f, and absorbed moisture, m_a, in the surface of the aggregate. Normally, m_a is about 1 percent. Therefore,

$$m = m_f + m_a = 1.01 m_f$$

When the aggregates appear porous, absorbed moisture may be much higher than 1 percent, in which case the percentage should be determined. Free surface moisture may be determined gravimetrically by

(a) Oven drying.
(b) Ignition loss of a mixture of moist aggregate and methylated spirits.
(c) Using proprietary moisture testing equipment.
(d) An inundation method.

If an air-entraining agent is used, the air content of air-entrained concrete should be measured by an air meter or by gravimetric procedure, and proper adjustment made as to the desired amount of the air-entraining agent to be introduced to the concrete mix.

Mixing

The order of mixing has some influence on the quality characteristics of the concrete. Concrete mixes of stiff consistency should only be prepared in a paddle or pan mixer. The strongest and most durable concrete is produced by first mixing sand and cement together, then adding water to the cement-sand mixture, and then adding the coarse aggregate. Revolving drum mixers in common use are not recommended for the type of mix under consideration. When their use is unavoidable, the order of mixing must be checked and altered if necessary to prevent balling of the mix. Total mixing time should generally be continued for 2 to 3 min, and that portion of the mixing time after all ingredients are in the mixer should continue for at least 1½ min.

PLACING AND FINISHING

Placing

The wearing course should be placed after the base slab has been prepared as described previously. In addition, if the wearing course is placed as soon as the base slab has become sufficiently firm to withstand foot pressure, or has set sufficiently so that water does not rise to the surface, but within 2 hr after placing, any water and laitance that has come to the surface of the base slab should be removed.

A convenient procedure is to place the base slab in the afternoon and the wearing course the next morning, thus allowing ample time for performing the several floatings which are necessary for optimum results. When the wearing

Courtesy Thor Power Tool Co.

Vibratory screed in action combining screeding and compacting operations at heavy loading area at railway receiving station

course is thus placed after the base slab has partially hardened, in addition to other preparation requirements, the base slab should be thoroughly wetted just prior to placing the wearing course, but pools of water should not be left standing on the wetted surface. A thin coat of neat cement slurry or grout should then be broomed onto the surface of the base slab for a short distance ahead of the topping such that the wearing course will be laid before the grout has hardened. When the wearing course is to be laid over a well matured base slab, the base slab should be soaked with water overnight or for an equivalent length of time.

If an integral waterproofing compound has been incorporated into the base-slab concrete, a small amount of wetting agent, approximately ¼ percent by weight of cement, may be added to the grout making it spread more easily.

If high-alumina cement is used for the surface course over a base course made with normal portland cement, the base course should be moist cured for about a week and then coated with a high-alumina cement slurry just before the surface course is laid.

Immediately after laying, the wearing course should be spread and brought to slightly above the designed grade by screeding or striking off with a straight-edge to allow for compaction.

Compacting

After striking off the wearing course to slightly above the designed grade, it should be thoroughly compacted by tamping or rolling, screeded again if necessary, and then floated until true to the designed grade by a power driven floating machine. The surface should be tested with a straightedge to detect high and low spots which should be eliminated.

Finishing by troweling alone

Floating should be followed by steel troweling after the concrete has hardened sufficiently to prevent moisture and excess fine material from being drawn to the surface. The finish should be brought to a smooth surface free from defects and blemishes. The trowel should give a ringing sound when drawn over the surface. The layer of fine material on the surface of the wearing course should be kept as thin as possible, because the calcium hydroxide and hydrated calcium aluminate formed during the setting of cement render it vulnerable to attack. For this reason, care should be taken to avoid:

1. Too early troweling.
2. Addition of water to facilitate troweling.
3. Dusting or sprinkling dry cement or a mixture of dry cement and stone dust or sand directly on the surface to absorb moisture or to stiffen the mix.

After the concrete has further hardened, additional troweling may be required depending on surface desired.

Finishing with an abrasive

Where a surface is desired which will not wear smooth, an abrasive such as silicon carbide may be added in an amount from 3 to 4 lb per sq yd during

final troweling, the finishing procedure prior to troweling being the same as troweling alone. The operation of adding the abrasive may be facilitated using a coarse sieve fitted with a piece of strong paper punched with ¼-in. diameter holes from 1 to 1¼ in. apart. The abrasive grains should be set firmly in the finish but should not be buried beneath the surface.

Finishing by grinding

Where finishing by grinding is required, surfaces should be swept with soft brooms, after rolling, to remove any water and surplus cement paste that may be brought to the surface. The wearing course is then floated and lightly troweled once. No attempt need be made to remove all trowel marks.

As soon as the wearing course has hardened sufficiently to prevent dislodging of aggregates, it is machine ground with rapid-cutting abrasive stones to expose the coarse aggregate. The surface should be kept wet during grinding, then squeegeed and flushed with water to remove ground-off material.

A cement slurry of creamy consistency should then be spread over the surface and worked into all air holes, pits, and other blemishes with a steel straightedge. The slurry is rubbed into the surface with the grinding machine. The wearing course should be kept moist for at least another 3 days, but the total time of curing should be not less than those recommended under curing below. The surface is then given a final grinding to remove the film and to give the finish a polish, then washed until all surplus material is removed.

Protection

All freshly placed concrete of the wearing course should be protected from the elements and from possible defacement due to other building operations. When necessary, all freshly finished concrete should be covered completely or enclosed by tarpaulins.

Weather precautions

If during the progress of work the temperature is, or will within 24 hr drop to, 40 F, the water and aggregate should be heated and precautions taken to keep the temperature of the concrete above 70 F for at least 3 days or above 50 F for at least 5 days.

When high-early-strength cement or other high-alumina cement is used, the temperature of the constituents at batching should not exceed 75 F and the concrete should not be placed while the shade temperature exceeds 85 F. If the temperature does not fall within these limits during the day, it may be necessary to place at night.

CURING

As soon as the surfacing concrete has hardened sufficiently to withstand defacement, it should be protected with at least 1 in. of wet sand, or other covering, to prevent premature drying. The covering should be kept wet for 1 to 2 weeks, depending on environment, when normal portland cement is used;

and for an additional week if low-heat portland cement is used. This period may be reduced to 3 to 10 days when high-early-strength cement or an accelerator is used. If possible, the longer curing is always to be preferred. The minimum curing period may be satisfactory in the beginning, but might result in an earlier and faster deterioration of the wearing course.

High-early-strength cement or high-alumina cement is rapid hardening and generates much heat during setting. To prevent the formation of pores and undesirable changes in crystal structure, water evaporation should be kept slow during the initial period of curing by watering sparingly and then by spraying or flooding with flowing water for the rest of the curing period.

Methods of membrane curing that may be applied over the wearing-course concrete to retard evaporation include:

1. Airtight sheathing of polyethylene membrane.
2. Colorless curing compound, or special oil.
3. Asphalt-impregnated, waterproof paper, with all seams overlapped and sealed with tape.

The effective hydration of cement through proper curing will substantially increase the strength, abrasion resistance, and durability of concrete; and will prevent drumminess and weakness from developing at the edges through premature drying and shrinkage of the surface. A period of drying after curing will improve the resistance of the cement to possible chemical attack. Preferably, a slab should not be put into service until it has dried for 1 week after curing if good service life is to be expected.

JOINTING

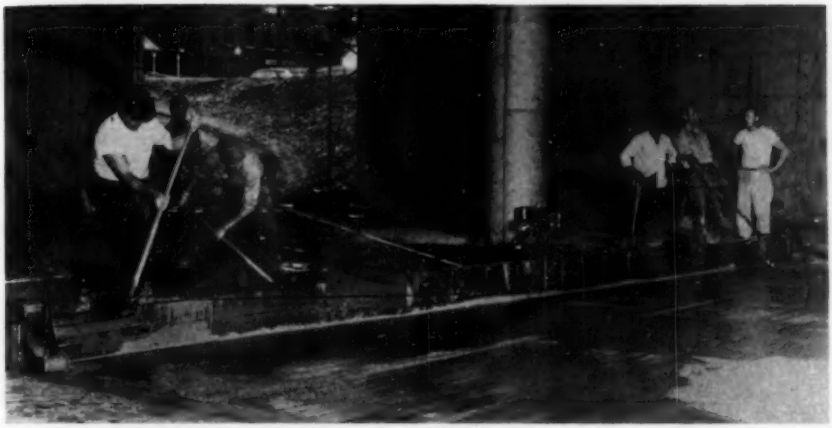
Joints in the wearing course should coincide with those in the base slab. The dimensions of such sections are determined by the tendency of the concrete to develop irregular shrinkage cracks. A crack in the base slab is likely to appear in the wearing course and reduce its service life.

If a concrete slab is to be exposed to the weather, it is preferable to limit the sections to 15-ft squares. If the slab is fully enclosed, such sections may be increased to about 20 ft square if the base slab is reinforced with light steel fabric.

Joints in the wearing course should be formed carefully by sawing without raising the edges above the surface.

Caulking

After the wearing-course concrete has cured and dried, the joints should be thoroughly cleaned, primed, and caulked. Caulking should be in two applications, with a mastic or bituminous rubber emulsion jointing compound. The compound should be firm, adhesive, ductile, and of low inherent shrinkage. The joints should be well maintained. Where joints are crossed by trucking lanes, they should always be filled with lead, or protected with a strip of rubber, copper, or soft brass.



Courtesy Stow Manufacturing Co.

Compacting and screeding warehouse floor with vibrating screed

SURFACE TREATMENTS

Surface treatments tend to seal the pores, act as a moisture barrier, and prevent dust formation. They are, however, not permanent and need periodic renewal. Along heavy traffic paths, the surface treatment should be increased in thickness or an additional coating applied. There is no surface treatment which can be depended on as a panacea. Where there is a weak, thickened, or uneven surface skin, it should first be ground off to eliminate subsequent local dusting and wear.

Surface treatments should be selected for a given slab wearing course according to relative merits, economics, and availability. Better useful service will be secured if they are properly applied. Liquid compounds should be applied after curing and drying of the wearing course. On a slab that will be subject to intense wear, it is advisable to leave the texture of the surface "off smooth" to provide a mechanical bond for a thick surface treatment.

A few surface-treatment materials and their methods of application are:

Metallic silico-fluorides—These consist of about four parts magnesium silicofluoride, one or more parts zinc silico-fluoride, and not more than one part lead or aluminum silico-fluoride. In using this treatment, the concrete should not contain an integral water-repelling agent or be cured with oil. Generally, three coats should be applied and covered 1 day later with two finishing coats of plasticized synthetic resin varnishes. The metallic silico-fluoride should be a 30 percent solution diluted with water to ⅓ concentration for the first coat, ½ concentration for the second, and used neat for the third. The application should be such that 1 gal. of undiluted 30 percent solution will cover

about 20 sq yd in each of the first two coats and about 30 sq yd in the third. Each coat must be sufficiently dried, or an interval of at least 4 hr be allowed between coats, to allow the succeeding coat to penetrate. After drying, the surface of the third coat should be washed thoroughly with water to remove any surplus solution. The reaction between the calcium hydroxide in portland cement and the metallic silico-fluorides tends to densify and harden the concrete by precipitating compounds in the pores but does not completely seal them. During the application of this treatment, good ventilation should be maintained, and operators must be positively warned to protect flesh wounds from contact with the solutions.

Plasticized synthetic resin varnishes—This group includes those containing polyvinyl chloride and acetate copolymer; phenol formaldehyde; cashew nut resin; furane; polystyrene; and epoxide, alkyd, or coumarone-type resins. Some have better adhesive qualities and more resistance to abrasion than others, depending on composition. Water must be kept off these preparations until they are completely set. Three coats of these preparations should be applied if used alone, or two coats if metallic silico-fluorides have been applied previously.

Bituminous seal—Bituminous seal should consist of a prime or tack coat and two protective coats. The tack coat should be first applied to the concrete surface to ensure bond for the subsequent coats. It should be a cutback bitumen with such consistency that each gallon will cover 6 to 7 sq yd when applied cold. It should be allowed to dry for at least 1 day even during warm weather. An alternate method is to have a thin uncovered continuous film of slow breaking bituminous emulsion applied just after initial set of the concrete to serve both as a curing medium and as the subsequent primer for the protective coats.

The first protective coat should be a thin layer of bituminous emulsion uniformly spread at the rate of 1 gal. to each 5 sq yd and immediately covered, before the emulsion turns back, with clean $\frac{1}{8}$-in. grit or coarse washed sand uniformly distributed at 1 cu yd per 160 sq yd and then lightly broomed and rolled.

After several hours, the excess unbound sand of the first protective coat should be carefully swept off, and a second protective coat of bituminous emulsion with covering, brooming, and rolling performed as for the first coat. Unbound material should be left on the surface for about a day after rolling to allow as much as possible to be worked into the bitumen by subsequent traffic. Then the excess material may be swept off.

Bituminous seals do not resist fruit juices, oils, fats, grease, and other organic solvents efficiently, particularly at higher summer temperatures. Their use should, therefore, be avoided where snack bars and refreshment counters may be installed at railway or bus depots.

Cold bituminous mastic mortar—This mortar should consist of a mixture of 1 part portland cement mixed dry with 4 parts clean, fine-to-medium sized sand, to which a small amount of water is added before stirring in 2 parts industrial bituminous emulsion.

A tack coat should be applied first. It is made by diluting industrial bituminous emulsion with about 5 percent cold water to reduce the emulsion to a thin brushing consistency, and should be spread at least 1¼ gal. per 100 sq ft to make it effective. The tack coat may take about ½ hr to dry, varying somewhat with weather conditions.

After the tack coat has dried, a layer of the bituminous mastic mortar of firm consistency should be applied to give a final depth of about ¼ in. The mortar should be tamped, screeded, and subsequently leveled with a wet, wood float. When the initial set has started a few hours later, as stresses tend to develop with loss of water, causing slight shrinkage, the surface should be back-troweled with a steel trowel to dissipate such stresses. As soon as the surface can be rolled without undue marking, it is advantageous to consolidate it with a hand roller, but not absolutely necessary. The slab should be cured for 24 hr with damp sawdust, sacking, or similar method. The slab can be put into service about a week after curing. Although slight indentations may be caused by early heavy trucking, the resulting marking will disappear and further traffic will improve the surface.

Where it is desired to have only heavy trucking aisles surfaced with cold bituminous mastic mortar, the mix can be worked out to a feather edge, but care must be taken so that it does not go beyond the tack coat, to keep adequate bond.

Where the slab will be continually wet and subjected at the same time to severe abrasion, as with an uncovered slab in a wet climate under heavy traffic, mastic-mortar surfacing should not be used.

REFERENCES

1. Lyse, Inge, and Holme, J. M., "Durability Studies of Concrete and Aggregates," ACI JOURNAL, V. 5, No. 2, Nov.-Dec. 1933 (*Proceedings* V. 30), pp. 121-128.

2. ACI Committee 804, "Concrete Wearing Surfaces for Floors," ACI JOURNAL, V. 10, No. 1, Sept. 1938 (*Proceedings* V. 35), pp. 21-32; Disc.—R. T. Giles, E. W. Scripture, Jr., F. E. Richart, C. B. Vannier, F. G. Baldwin, and Committee, V. 10, No. 7, June 1939 (*Proceedings* V. 35), pp. 32-1–32-15.

3. Wästlund, Georg, and Eriksson, Anders, "Wear Resistance Tests on Concrete Floors and Methods of Dust Prevention," ACI JOURNAL, V. 18, No. 2, Oct. 1946 (*Proceedings* V. 43), pp. 181-200.

4. "Design and Control of Concrete Mixtures," 10th Edition, 1952, Portland Cement Association, Chicago, 68 pp.

5. "Specifications for Heavy-Duty Concrete Floor Finish," *Concrete Information* ST-69, Structural and Railways Bureau, Portland Cement Association, Chicago.

6. "Design of Concrete Mixes," The United Kingdom Department of Scientific and Industrial Research, London.

7. "Design, Control, and Characteristics of Concrete," Cement and Concrete Association of Australia, Sydney.

8. *ASTM Standards 1955*, Part 3, American Society for Testing Materials, Philadelphia.

9. Taylor, W. H., "Durable Floors for Factories," *Report* No. R-7, Division of Building Research, Commonwealth Scientific and Industrial Research Organization, Melbourne, 1956.

10. *ASTM Standards, 1956 Supplement*, Part 3, American Society for Testing Materials, Philadelphia.

11. *ASTM Standards, 1957 Supplement*, Part 3, American Society for Testing Materials, Philadelphia.

Received by the Institute Apr. 21, 1958. Title No. 55-57 is a part of copyrighted Journal of the American Concrete Institute, V. 30, No. 8, Feb. 1959 (Proceedings V. 55). Separate prints are available at 50 cents.

American Concrete Institute, P. O. Box 4754, Redford Station, Detroit 19, Mich.

Discussion of this paper should reach ACI headquarters in triplicate by May 1, 1959, for publication in the Part 2, September 1959 JOURNAL.

Title No. 55-58

SPECIFIC SURFACE OF AGGREGATES Applied to Mix Proportioning

By B. G. SINGH

SUGGESTED PROPORTIONING METHOD, applicable to both continuous and gap-graded aggregates, uses specific surface of aggregate as an index of grading. Two charts are offered for use with this method. After selecting the W/C ratio to give a required strength, the first chart is used to choose an aggregate-cement ratio that will give desired consistency at the selected W/C. From the second chart a specific surface corresponding to the aggregate-cement ratio is chosen to allow for slightly higher or lower sand content. The fine and coarse aggregate are combined (as illustrated) to give the required specific surface. Charts are for irregular, ¾ in. maximum size aggregate, but charts for proportioning with other types and sizes of aggregate may be similarly developed.

THERE ARE VARIOUS METHODS OF PROPORTIONING for general purposes. In Great Britain type-grading curves are usually chosen as a basis of concrete mix design, whereas in the United States the fineness modulus is chosen. Both methods are reliable with aggregates containing all or most of the aggregate size groups as determined from the same analysis, but become less reliable or inapplicable with other aggregates.

It can be shown that there is a close connection between various grading indices and the specific surface, limitations of these grading indices with "unusual" gradings may be due to their inability to give sufficient recognition to variations in specific surface. However, attempts made by Edwards,[1] and later by Young,[2] between 1918 and 1920 to base concrete mix proportioning on the surface area of aggregates, did not find favor and were little used.

Two earlier papers[3,4] indicate that, provided harshness is avoided, the strength and consistency of concrete are reasonably constant if the specific surface is constant. This, it might be emphazised, is quite independent of the particle size distribution. The important implication of this fact is that the specific surface as an index of grading is applicable to a wider range of grading than the type-grading curves or the fineness modulus.

B. G. SINGH is with Jamaica Engineering and Research Co., Ltd., Jamaica, West Indies. A member of ACI, Dr. Singh has written several papers which have appeared in the JOURNAL; the latest, "Aggregate Grading Influences Air Entrainment," appeared in January.

It should be possible to modify concrete mix proportions based on other grading indices if these indices could be related to specific surface for their range of application and then be extended. For example, it is easy to estimate the specific surface corresponding to a given type-grading curve and then to obtain other gradings with an equivalent specific surface, and with these to proportion concrete mixes as suggested.

CHOICE OF AGGREGATES

Provided that the particles of the aggregates are clean, resistant, durable, and the dust content (that passing the No. 100 sieve) limited to a few percent, good concrete can be made with a wide range of grading and the choice of aggregates should largely be a question of economy.

Combined aggregates with one or more size groups absent are normally called gap-graded aggregates. Each size group absent is considered one gap. Such aggregates with two or three successive gaps (within the extreme size groups) suffer a few disadvantages compared to continuous grading. As a general rule, three successive gaps should be avoided for wet mixes as there is a marked tendency for such mixes to segregate. However, if concrete of stiff consistency is required and is to be placed by vibration the latter grading may even be used with advantage and give properties not obtainable with continuous grading.

As the sand in the mix becomes finer, a lower percentage is required. The coarse aggregates pack closer (compare A and B of Fig. 1). However, to avoid harshness, higher aggregate specific surface is required. The use of a lower sand content might be desirable in view of lower cost of coarse aggregate, though the use of a higher specific surface will require a higher water-cement ratio to maintain a given consistency, which could involve the use of a slightly richer mix.

Rounded aggregates have a lower specific surface for a given particle size distribution, and a lower specific surface (less sand) could be used, which, in effect, could mean a saving in cement. Therefore aggregate shape also plays an important part in selection.

Control of aggregate specific surface and water-cement ratio in a mix becomes more difficult as the sand becomes finer, for two main reasons. First, a variation in batching could lead to a more significant variation in specific surface, and second, the water content in the sand under practical storage conditions could be more variable. In general, the quality of concrete made with such material will require greater control and this should be considered in relation to the price of such materials.

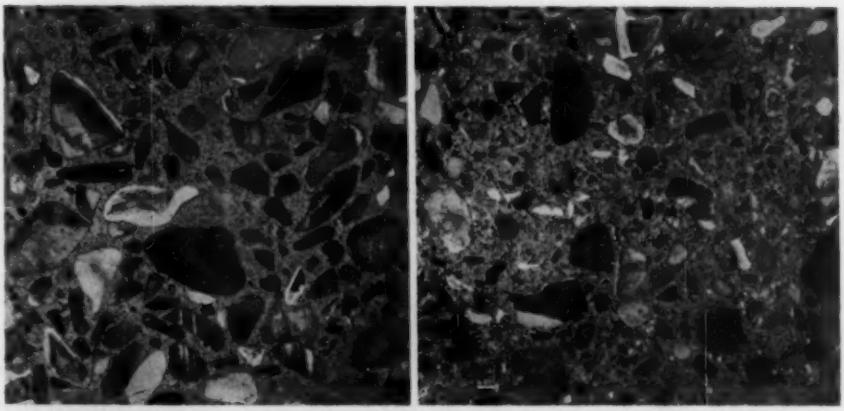
Proportions of fine and coarse aggregate

The proportioning of fine and coarse aggregate is still somewhat arbitrary and is not related to specific requirements as it should be. Apart from methods that specify a 1:2 fine to coarse aggregate ratio, other more recognized methods of mix proportioning are somewhat indefinite on this point and it is left to choice. This, to a certain extent, is understandable as factors influencing the fine to coarse aggregate ratio are numerous. However, fine aggregate content for a given maximum aggregate size and shape is mainly influenced by the following factors:

(a) Aggregate-cement ratio
(b) Grading of the sand
(c) Consistency and method of placement
(d) Ratio of volume of concrete to its smooth area (both internal and external)

Although (a) and (b) could be investigated within limits, (c) and (d) will vary from job to job. Thus, any relationship drawn up for fine aggregate requirements for (a) various mixes and (b) sand grading will have to allow a suitable variation lest the relationship have little practical significance.

As a mix is made richer and the sand gets finer, less of it could also be used with advantage. A sand content for example, suitable with an aggregate-cement ratio of 6 will produce a rather fat concrete with, say, an aggregate-cement ratio of 3; conversely a suitable sand content for an aggregate-cement ratio of 3 will make a rather harsh concrete with an aggregate: cement ratio of 6. The aim in fixing this ratio should be to keep the specific surface at a minimum



A (left)—Grading No. 7, having 24 percent between No. 52 and No. 100 sieves, 38 percent between ⅜ and 3/16 in., and 38 percent between ¾ and ⅜ in. B (right)—Grading No. 5, having 11.2 percent between each of the following sieves: No. 52 and No. 100, No. 25 and 52, No. 14 and No. 25, No. 7 and No. 14, and No. 7 and 3/16 in., and having 22.0 percent between ⅜ and 3/16 in., and 22.0 percent between ¾ and ⅜ in.

Fig. 1—Showing that coarse aggregate packs closer as the sand in a mix becomes finer. Mix 1:6 by weight, water-cement ratio, strength, and consistency are constant

yet to avoid harshness as this will give a required strength and consistency with the least cement.

Fine sand with two or three successive gaps allows the coarse aggregate to pack closer (see Fig. 1) and as a result a smaller percentage is required, though a suitable specific surface for the combined aggregate must be somewhat higher to avoid harshness. As with gradings with no gaps, the fine aggregate content (and therefore the specific surface of the combined aggregate) must be increased as the aggregate-cement ratio of the mix is increased.

The range of appropriate specific surface values applicable to continuous and gap-graded sands for various aggregate-cement ratios, (aggregate of ¾ in. maximum size) have been examined and a relationship obtained (Fig. 2) that should be acceptable for most purposes. This may have to be modified in the light of further experience.

For a range of mixes normally used, Zone 1 of Fig. 2 indicates a range of acceptable specific surface values for aggregates with one or no gaps. The lower limit is suitable for mixes with lower sand contents and the higher limit for mixes requiring more sand and with an increasing dust content. For a straight graded sand between the No. 100 and the 3/16-in. sieve sizes, it could vary by about 8½ percent within the zone. This range should be adequate for most purposes for any given mix.

Zone 2 indicates a range of acceptable specific surface values, for aggregates with two or three gaps, and for the normal aggregate-cement ratios. As for Zone 1, lower and higher specific surface levels are given to allow for low and high sand contents and when dust is present in the aggregate. Zone 2 allows a

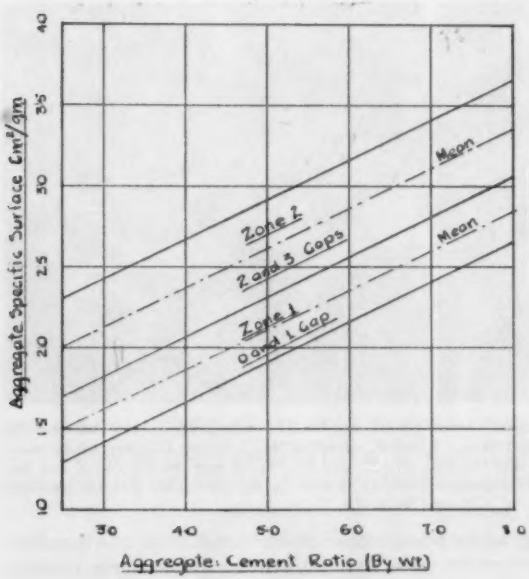


Fig. 2—Relationship of specific surface and aggregate-cement ratio for continuous and gap-graded aggregates, ¾ in. maximum size, river or pit

variation of about 6½ percent with a sand straight graded between the No. 100 and the No. 25 sieves. It should be noted that mixes of especially stiff consistency, made with sand with two or three of its coarser size groups absent, show an apparent harshness which disappears with compaction.

METHOD OF COMBINING FINE AND COARSE AGGREGATE TO GIVE A REQUIRED SPECIFIC SURFACE

For convenience aggregate passing the 3/16-in. sieve is usually denoted fine, and that retained, as coarse. If the weights of various size groups present in a fine aggregate are given by A_1, A_2, A_3, etc., and the corresponding specific surface is given by S_1, S_2, S_3, etc., then its specific surface is then given by:

$$S_f = \frac{A_1 S_1 + A_2 S_2 + A_3 S_3 + \ldots\ldots + A_6 S_6}{A_1 + A_2 + A_3 + \ldots\ldots + A_6} \quad \ldots\ldots\ldots\ldots (1)$$

The specific surface of the coarse aggregate can be calculated similarly.

The specific surface of the various size groups can be determined by the water permeability method or an estimation made on the basis of a shape factor (see Discussion). In carrying out this test, the six groups should be effectively separated. Failure to do so will result in variation. Values obtained for effective sieving by this method, that are likely to have more general application for aggregate classified as irregular by British Standard 882:1947, are given in Table 1.

TABLE 1—SPECIFIC SURFACE OF VARIOUS SIZE GROUPS OF AN IRREGULAR AGGREGATE

Passing	Retained	Sq cm per g	Remarks
No. 100 sieve	No. 200 sieve	260	—
No. 52 sieve	No. 100 sieve	128	—
No. 25 sieve	No. 52 sieve	65	—
No. 14 sieve	No. 25 sieve	35	—
No. 7 sieve	No. 14 sieve	16	—
⅛-in. sieve	No. 7 sieve	8	—
⅜-in. sieve	⅛-in. sieve	4	Estimated
¾-in. sieve	⅜-in. sieve	2	Estimated

After making a sieve analysis of the fine and coarse aggregate, their specific surfaces can be estimated using Eq. (1) and the above values. An adjustment must be made for a variation in shape (see Discussion).

The percentage fine aggregate content F_a (by weight) of specific surface S_f which must be combined with coarse aggregate of specific surface S_c to give a required specific surface S_o is given by:

$$F_a = 100 \frac{(S_o - S_c)}{(S_f - S_c)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The percentage coarse aggregate is $100 - F_a$.

SELECTION OF SUITABLE AGGREGATE-CEMENT RATIO

The choice of aggregate-cement ratio is mainly influenced by strength and consistency requirements. Though both strength and consistency are affected by the specific surface of aggregates, provided that the range of specific sur-

face is suitably restricted (as in Fig. 1), strength can be considered, for practical purposes, as related to the water-cement ratio. Similarly consistency can be also considered constant for small variations in specific surface.

Using the compacting factor (CF)* as an index of consistency, it has been shown[3] that:

$$CF = \frac{W/C}{1.21P + 0.0005\,NS_o + 0.0604\,N \times W/C} \quad \ldots\ldots\ldots\ldots (3)$$

where

W/C = water-cement ratio by weight
P = water-cement ratio by weight for standard consistency as required by B.S. 12:1947
N = aggregate-cement ratio by weight
S_o = specific surface of the aggregate in sq cm per g

A variation in S_o of ± 3 sq cm per g in Eq. (3) will produce a variation of 0.01 in CF, which is within the bounds of reproducibility of a CF test. A variation of specific surface of this order could be considered as having little effect on consistency. Thus a mean for each zone in Fig. 1 can be used, as the variation of specific surface (± 2 sq cm per g for Zone 1 and ± 3.0 sq cm per g for Zone 2) within each will not affect consistency significantly.

The effect of cement on the consistency of concrete is important and cannot be explained in terms of P alone. Until more is known, a value of P = 0.280 can be used as this is likely to be on the safe side, i.e., estimated CF values are likely to be slightly lower than the CF test values, when the cement P value is less than 0.280. However, higher P values should be used if tests show that it exceeds 0.280.

Using P = 0.280 and the mean S_o for Zones 1 and 2 (Fig. 1) for the given range of N ratios, W/C corresponding to CF = 0.75, 0.85, 0.90, 0.95, and 1.00 were calculated from:

$$W/C = \frac{0.339 + 0.0005\,NS_o}{\frac{1}{CF} - 0.0604N} \quad \ldots\ldots\ldots\ldots (4)$$

The above range of CF is generally assumed to correspond to slumps 0-1 in., 1-2 in., 2-4 in., and 4-8 in., respectively. In Fig. 3, W/C is related to N for four zones of consistency both for aggregate of one or no gaps (shown by full lines) and for aggregate of two or three gaps (shown by dashed lines). Note that mixes with CF values approaching 1.00 will exhibit a marked tendency to segregate.

*In the compacting factor test, concrete is allowed to compact itself by falling under standard conditions. The density achieved is expressed as a ratio to the density of the fully compacted concrete. Thus concrete of greater plasticity will give a higher CF value.

PROPORTIONING THE MIX

Fig. 2 and 3 can be used as follows. A suitable W/C value is selected to give a required strength. Depending on the consistency required, an aggregate-cement ratio is selected from Fig. 3. A specific surface corresponding to this aggregate-cement ratio is selected from Fig. 2, allowing for a high or low sand content. The fine and coarse aggregate can then be combined as suggested to give the required specific surface. A trial mix can be made for confirmation.

From the selected W/C and N values, the cement C (by weight) required per cubic yard of concrete can be estimated from the following:

$$C = \frac{1685\, G_a\, G_c\, (1.00 - V_a)}{G_c\, [(W/C)\, G_a + N] + G_a} \qquad (5)$$

where
G_a = average specific gravity of the aggregate
G_c = specific surface of the cement
V_a = air present per unit volume of concrete

For materials similar to that of the present investigation, G_a and G_c can be taken as 2.63 and 3.12, respectively. Though V_a will vary with N and W/C, an average value of 0.015 can be taken. Having determined C, weight of aggregate and water per cubic yard are CN and $C\ (W/C)$ respectively.

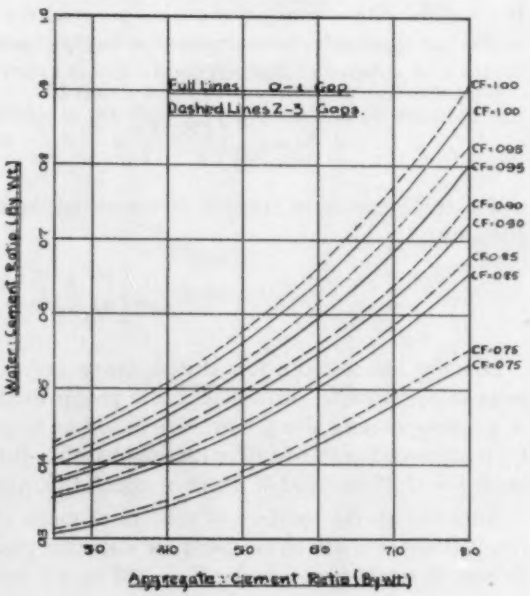


Fig. 3—Water-cement ratios for mixes with aggregates of the mean specific surface shown in Fig. 2. Four zones of consistency are shown

DISCUSSION

Although the method of proportioning put forward in this paper is restricted to the type and maximum aggregate size used by the author, the method should have equal application to other types and maximum aggregate sizes. Available and additional data should be analyzed with a view to drawing up relationships such as those given in Fig. 2 and 3. If this is done, the design of concrete will be both rationalized and simplified.

Problem of determining specific surface

A disadvantage of the method outlined is the additional test for determining the specific surface of the various size groups of an aggregate by the water permeability method. However, this should not be unduly troublesome if sufficient tests are carried out to classify aggregates from various supplies in relation to specific surface. Then the specific surface can be estimated to a required degree of accuracy by a simple grading test, and permeability tests can be carried out from time to time to check for variation in specific surface within any given size group.

Meanwhile, any method of obtaining an approximation of the specific surface of aggregates should be of some value. Young[2] has used an index of grading which he called surface modulus. In obtaining this value he used sieves with apertures related as 1:2:4:8: etc. (approximating British sieves used in concrete work). Under such conditions the specific surface of spherical particles of the various size groups are related as 1:½:¼:⅛: etc. Thus, if the spheres are of the same specific gravity and distribution within any given size group, S the specific surface of the smallest size group (i.e. between the No. 100 and No. 200 sieves), and p_1, p_2, p_3, etc., the percent weight of six groups in the fine aggregate, from smallest to largest, then the specific surface of a combination of spheres of fine aggregate size is given by:

$$S_f = \frac{S}{100}\left(\frac{P_1}{1} + \frac{P_2}{2} + \frac{P_3}{4} + \frac{P_4}{8} + \frac{P_5}{16} + \frac{P_6}{32}\right) \quad \ldots\ldots (6)$$

and a combination of spheres of coarse aggregate size (¾ in. maximum) is given by:

$$S_c = \frac{S}{100}\left[\frac{P_7}{64} + \frac{P_8}{128}\right] \quad \ldots\ldots (7)$$

Loudon[5] has tested a few British sands and expressed their angularity as a ratio of the specific surface of a size group to the specific surface of spheres of a corresponding size group. He found an angularity factor f varying from 1.1 for rounded sand to 1.6 for crushed basalt. He suggests $f = 1.1$ for rounded sand, $f = 1.25$ for sand of medium angularity, and $f = 1.4$ for angular sand.

Since the specific surface of spheres of mean size between the No. 100 and No. 200 sieves is 210 sq cm per g for a specific gravity of 2.65, an estimation of S_f and S_c could be made for $S = 210$ sq cm per g from Eq. (5) and (6), re-

spectively, and multiplying by an appropriate shape factor f. A good estimation of specific surface can be made for the type of material used in the present investigation if $f = 1.25$ is assumed. Intelligent interpolation of values between $f = 1.1$ and 1.25 in Eq. (5) and (6) as the aggregate gets less angular will enable a reasonable estimation of specific surface to be made, and Eq. 2 can be used to combine the fine and coarse aggregate as required.

ACKNOWLEDGMENTS

The author is indebted to the Director of Building Research, Department of Scientific and Industrial Research, Watford, Herts, England, and to Prof. H. J. Collins of University College, London, for facilities and other useful assistance in carrying out the research described in this paper.

REFERENCES

1. Edwards, L. N., "Proportioning the Materials of Mortars and Concretes by Surface Areas of Aggregates," *Proceedings*, ASTM, V. 18, Part II, 1918, p. 235.

2. Young, R. B., "Some Theoretical Studies on Proportioning Concrete by the Method of Surface Areas of Aggregates," *Proceedings*, ASTM, V. 19, Part II, 1919, p. 444.

3. Singh, B. G., "Effect of the Specific Surface of Aggregates on the Consistency of Concrete," ACI JOURNAL, V. 28, No. 10, Apr. 1957 (*Proceedings* V. 53), pp. 989-998.

4. Singh, B. G., "Specific Surface of Aggregates Related to Compressive and Flexural Strength of Concrete," ACI JOURNAL, V. 29, No. 10, Apr. 1958 (*Proceedings* V. 54), pp. 897-908.

5. Loudon, A. G., "A Laboratory Study of the Permeability of Sand," *Geotechnique*, V. 3, No. 4, pp. 165-183.

Received by the Institute Oct. 21, 1957. Title No. 55-58 is a part of copyrighted Journal of the American Concrete Institute, V. 30, No. 8, Feb. 1959 (Proceedings V. 55). Separate prints are available at 50 cents.

American Concrete Institute, P. O. Box 4754, Redford Station, Detroit 19, Mich.

Discussion of this paper should reach ACI headquarters in triplicate by May 1, 1959, for publication in the Part 2, September 1959 JOURNAL.

CONCRETE BRIEFS

Notes from Field and Office

Predicting 7- to 28-Day Compressive Strength Gains of Concrete . . 903

Some Effects of Carbon Dioxide on Mortars and Concrete—Discussion 905

Problems and Practices 908

Predicting 7- to 28-Day Compressive Strength Gains of Concrete

By E. L. HOWARD* and K. K. GRIFFITHS†

Lacking a "seerstone," the designer must rely on his knowledge of the characteristics of cement and aggregate and the efficiency of the batching plant in proportioning a guaranteed strength concrete. With all this foreknowledge, providing there are no difficulties due to sampling and testing methods, the designer feels secure in the hope for good strengths in 28 days. If 1200 to 1500 psi is added to the 7-day test results, a close approximation of 28-day compressive strength is obtained. There are times, however, when the gain in concrete strengths after 7 days is less than 500 psi. These occasions leave the designer helpless with last month's work subject to rejection.

An example of this problem are the strengths of daily concrete samples plotted in Fig. 1. The samples were taken from the transit mix trucks at the point of delivery. The guaranteed strength of 3500 psi is met until late June. At this point the 28-day test cylinders fail to gain strength as before, and they fall below the guaranteed minimum. Knowledge that something is amiss came too late to apply a remedy. The designer needs a device that can alert him early enough to take preventive action.

The purpose of this test program was to find a "crystal ball" to predict the strength gain. To accomplish this end, 15 trial batches of concrete were made using mill tested cements and standard commercial aggregates. The cement for each batch was a composite of mill control samples taken during a day's run (Table 1). Aggregates were sampled at a batch plant yard from incoming railroad car shipments. The test data on the sand and ¾ x ¼ washed gravel are detailed in Table 2. All the materials used met the standard specifications for concrete materials.

TABLE 1—TEST DATA SUMMARY OF DAILY COMPOSITE SAMPLES OF CEMENT

	Typical	Maximum	Minimum
C_3S	41	46	37
C_2S	30	33	24
C_3A	11.7	14.1	10.2
C_4AF	10.1	10.3	7.7
Compressive strength, psi			
3 day	2420	2828	2225
7 day	3347	3686	2931
28 day	4256	4655	3745

In the trial batches, a w/c of 6¾ gal. per

A part of copyrighted JOURNAL OF THE AMERICAN CONCRETE INSTITUTE, V. 30, No. 8, Feb. 1959 (*Proceedings* V. 55). Separate prints of the entire Concrete Briefs section are available at 35 cents each. Address P. O. Box 4754, Redford Station, Detroit 19, Mich.

*Member American Concrete Institute, Chief Testing Engineer, Pacific Cement and Aggregates, Inc., San Francisco, Calif.

†Assistant Testing Engineer, Pacific Cement and Aggregates, Inc., San Francisco, Calif.

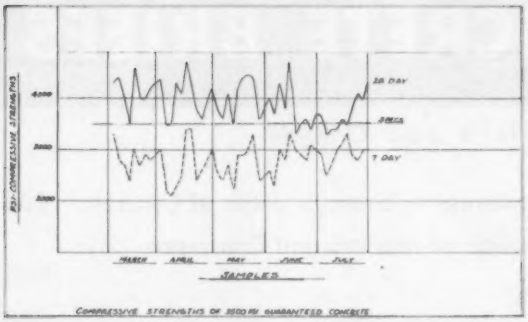


Fig. 1—Strengths at 7 and 28 days of samples of a 3500-psi guaranteed concrete taken from the transit mix truck at point of delivery

sack was used for the 6-sack mix with ¾ in. maximum aggregate. Mixing time after all ingredients were batched was 5 min.

Air determination, Kelly ball readings, unit weight checks, and temperature readings were made of each batch. From one portion of each batch, 4 x 8-in. cylinders were made for compression tests to break at 3, 7, 14, and 28 days. A portion of each batch was wet-screened through the ¼-in. sieve before casting into 4 x 8-in. cylinders. This group was also broken at 3, 7, 14, and 28 days. From each batch, before screening, two 6 x 12-in. cylinders were cast for a 28-day compression test.

The 15 batches, identical as to proportions and w/c, are rated excellent in uniformity of control. The within-batch variations are 3.7 percent for 4 x 8-in. cylinders and 2.4 percent for 6 x 12-in. cylinders, based on "Recommended Practice for Evaluation of Compression Test Results of Field Concrete (ACI 214-57)."

The average strengths at the several ages for the 15 concrete batches are plotted in Fig. 2. Note that the $-¼$-in. mortar reaches higher strength than concrete. (The $-¼$-in. mortar and concrete are from the same batch, the one having the $+¼$-in. aggregate removed before casting in the cylinder molds.)

Each of the tests (other than strength tests) made in this study were considered for a measure as a "crystal ball." None of these data seemed to have a relationship to strength.

The earliest age that strength is normally measured is in the 3-day mortar test made at the cement mill. Data were prepared to discover a possible clue to the expected gain from 7 to 28 days. No apparent useful relationship exists between the 3 to 7 and the 7 to 28 day increases in strength.

The efficiency of a batching plant is measured by an evaluation of the compression test results (ACI 214-57). The designer will find 15 percent deviation not unusual at the efficient batch plant. This study adds some

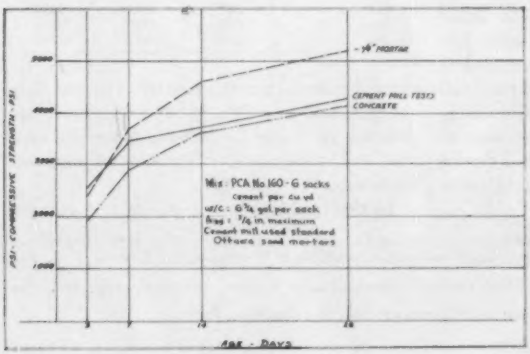


Fig. 2—Average strengths at several ages for 15 concrete batches

data as to the part cement may play in the variance of concrete strengths on the job.

TABLE 2—TEST ANALYSIS OF AGGREGATES SAMPLED AT BATCH PLANT

Aggregate size, U. S. sieves	Percent passing	
	¾ x ¼	Sand
1	100	
¾	96	
½	58	
⅜	30	
4	2	99
8		75
16		55
30		40
50		17
100		5
200		1.5
Specific gravity	2.70	2.67
Percent absorption	1.3	1.6
Sand equivalent		82
LAR loss at 500 revolutions	28	

The coefficient of variation determined from the cement mill mortar compression tests averages 7.4. This is a sizable contribution to the control problem on the job.

We are convinced there is no magic formula equal to the task of predicting concrete strengths. Nothing we have found so far can replace careful inspection and control working in hand with accurate evaluation of test results. Two conclusions, certainly not all new ideas, can be drawn from this study:

1. The percentage of strength gain in the 3 to 7-day period of cement mill mortars does not presage the 7 to 28-day strength gain in concrete.

2. Variations in potential strength from lot to lot of cement can increase the required safety factor for concrete.

Some Effects of Carbon Dioxide on Mortars and Concrete—Discussion

By HAROLD H. STEINOUR*

Steopoe[1] recently presented a brief discussion of the 1956 ACI JOURNAL paper by Leber and Blakey[2] on effects of carbon dioxide on mortars and concretes. In his discussion he calls attention to his early work[3] in which he demonstrated that carbon dioxide acting on hydrated portland cement forms acid-insoluble silica. The present discussion offers further comment on that matter, and considers also the extent of carbonation that is theoretically possible.

Steopoe's early paper is of even greater interest than he brought out, for he obtained his result by exposure of porous specimens of hydrated cement to room air. That is, the CO_2 pressure was only that present in the atmosphere (about 0.0003 atmosphere in rural outdoor air, but sometimes as high as 0.0012 atmosphere in unventilated rooms). Thus, except for the fact that he used porous specimens (obtained by use of a little calcium carbide in the mix), his results are for normal exposure. He obtained accelerated attack owing to the high porosity, but he demonstrated that where a surface of hydrated portland cement *is* exposed to the air the carbonation can decompose calcium silicate and produce free hydrous silica (that being the only siliceous product that would not be acid soluble).

This result may be compared with the following statement by Lea.[4] "The ultimate fate of any cement product stored in air is to become converted to calcium carbonate and hydrated silica, alumina, and ferric oxide, since all cement compounds are decomposed by carbon dioxide. This action under ordinary conditions is limited, however, to the exposed surfaces of mortars and concretes and does not penetrate the inner mass." Similar statements regarding decomposition to hydrated silica, alumina, and ferric oxide are also to be found elsewhere in the literature. Nowhere, however, has the writer found any demonstration (theoretical or experimental) that this complete decomposition of the calcium compounds of hydrated portland cement can actually be brought about in the

*Member American Concrete Institute, Assistant to the Director of Research, Portland Cement Association, Chicago, Ill.

normal atmosphere. Steopoe's work, however, provides experimental demonstration relative to production of hydrous silica.

As to alumina, it is known that when alkali aluminates are treated with CO_2 gas, aluminum hydroxide is precipitated,[5] but similar data for treatment with ordinary air appear to be lacking. It has also been reported that calcium ferrite is decomposed by CO_2 gas, with formation of red hydrated ferric oxide,[6] but here too the applied pressure of CO_2 greatly exceeded that in the atmosphere. Also to be considered is the effect of CO_2 on calcium sulfoaluminate.

From the theoretical side, it is definite of course that, with the exception of sulfate, all calcium compounds in hydrated portland cement are salts of weak acids and therefore hydrolyze with production of calcium hydroxide in solution. It is thus to be expected that carbon dioxide at any pressure within the range which precipitates calcium carbonate in the system CaO-CO_2-H_2O will cause some decomposition of these calcium compounds. The minimum CO_2 pressure for the $CaCO_3$ range at ordinary temperature is about 10^{-14} atmospheres.[7] Since the pressure of CO_2 in outdoor air is 0.0003 atmosphere, some decomposition is assured. However, unless it were definitely established that there were no lower-limed stages between the hydrated calcium compounds as they exist in hydrated cement and the ultimate stage of conversion to the respective free "acids" (i.e., hydrous silica, alumina, and ferric oxide) the decomposition need not be complete. That is, some further evidence is needed to reach such a conclusion. Actually, it is known that intermediate stages do exist.

This situation led the writer to seek a general criterion by which it might be possible to determine from existing data whether such complete carbonation of portland cement, as Lea's statement assumes, is theoretically possible.

If a calcium salt of a weak nonvolatile acid in the presence of a meager amount of water does completely carbonate, there remains finally only $CaCO_3$, solid acid, and the aqueous solution at the existing CO_2 pressure, which may be taken as 0.0003 atmosphere. In the solution, the ion activity product $(Ca^{++})\,(OH^-)^2$ will have a constant value. This follows from the fact that $CaCO_3$ maintains a constant solubility product (Ca^{++}) (CO_3^{--}), and (CO_3^{--}) can be expressed in terms of $(OH^-)^2$ by use of the over-all acid dissociation constant for carbonic acid, the pressure of CO_2, and the constancy of the ion product $(H^+)\,(OH^-)$ for water. Established constants give the following result at ordinary temperature, where P is the pressure of CO_2 in atmospheres:

$$(Ca^{++})\,(OH^-)^2 = \frac{7.2 \times 10^{-19}}{P}$$

In this case P is 0.0003, and $(Ca^{++})\,(OH^-)^2$ is 2.4×10^{-15}.

Whether a calcium salt such as calcium silicate, aluminate, or ferrite completely carbonates depends, therefore, on whether or not it establishes a higher value of $(Ca^{++})(OH^-)^2$ at the point in its own phase system, CaO-acid oxide-H_2O, where the solid acid and the lowest-limed calcium salt of that system are in equilibrium with solution. That it will, indeed, establish a definite value is evident by analogy with the system CaO-CO_2-H_2O. If this value is greater that 2.4×10^{-15} then complete decomposition by CO_2 can occur, for even the lowest-limed calcium salt must decompose through further formation of $CaCO_3$, so that the product $(Ca^{++})\,(OH^-)^2$ can reduce to the value 2.4×10^{-15}) and thus attain equilibrium with the CO_2 pressure.

Such data as are available on the pertinent phase systems lend themselves to approximate computation of $(Ca^{++})\,(OH^-)^2$ since the calcium in solution has usually been determined analytically, and pH has also sometimes been determined. Where it has not, a safe value of (OH^-) can generally be readily estimated either because the solution is obviously mainly calcium hydroxide or because it is safe to assume negligible undissociated acid in solution. In the latter case, the (Ca^{++}) $(OH^-)^2$ value will be too low, so if found to be higher than 2.4×10^{-15} complete carbonation is assured. In other cases, known dissociation constants can be brought into the calculation.

Data for the systems CaO-SiO_2-H_2O,[8] CaO-Al_2O_3-H_2O, and CaO-Al_2O_3-$CaSO_4$-H_2O[9] indicate that, in ordinary air, carbonation can indeed proceed until the silica and alu-

mina are completely converted to the hydrous oxides. For the system CaO-Fe_2O_3-H_2O, data are meager, but what there are[10] suggest that here too, exposure to ordinary air can be expected to produce the acid, i.e., hydrous ferric oxide. It may seem peculiar to think of hydrous alumina and ferric oxide as acids, but aluminum hydroxide is distinctly amphoteric and ferric oxide is slightly so. Both may therefore be regarded as either acids or bases, according to circumstances.

An interesting situation arises with respect to the small amount of MgO in cement, which is there mainly as the free oxide. At 18 C, the lowest CO_2 pressure at which magnesium carbonate, $MgCO_3 \cdot 3H_2O$, precipitates in the system MgO-CO_2-H_2O, has been reported as 0.00037 atmosphere.[11] Below that, the hydroxide, $Mg(OH)_2$, precipitates. Since the value may not be strictly accurate, and since the CO_2 in the atmosphere varies somewhat with local conditions, it is debatable whether or not the magnesia will carbonate. Indoors it may well do so but outdoors it may not.

This study[12] has indicated that all the CaO in portland cement except that assignable to $CaSO_4$ can probably be converted to $CaCO_3$, not only at one atmosphere of CO_2 but at the much lower concentration of CO_2 in ordinary air. However, the study provides no information as to the extent or depth to which the reactions may actually occur in practice. For the purpose of the calculations, it was assumed throughout that free water was present and that the solids were freely exposed so that reaction could progress as it would if a powder were stirred in a laboratory beaker with water kept saturated with carbon dioxide at the pressure concerned. In good dense concrete the reaction would only be superficial, as Lea has stated.

The conclusions regarding the theoretically possible degree of combination with carbon dioxide may be stated as follows:

To estimate the carbon dioxide required for the theoretically possible total carbonation at one atmosphere pressure of CO_2, compute CO_2 for conversion of all CaO except that in $CaSO_4$ to $CaCO_3$, all MgO to $MgCO_3$, all Na_2O to $NaHCO_3$, and all K_2O to $KHCO_3$. The factors for computing this CO_2 are as follows:

$0.785 \times$ (percent CaO $- 0.7 \times$ percent SO_3)
$1.091 \times$ percent MgO
$1.420 \times$ percent Na_2O
$0.935 \times$ percent K_2O

The carbon dioxide required for carbonation at the pressure of CO_2 in ordinary air may be somewhat less than as calculated above, owing to possible failure of MgO to carbonate, and partial formation of Na_2CO_3 and K_2CO_3 instead of bicarbonates. A minimum total can be computed by assigning no CO_2 to MgO and using factors half as large as those given above for Na_2O and K_2O. The factor for CaO would remain as above. In all cases, the free CO_2 or H_2CO_3 in solution can be regarded as negligible.

REFERENCES

1. Steopoe, A., "Some Effects of Carbon Dioxide on Mortars and Concrete—Discussion," ACI JOURNAL, V. 29, No. 11, May 1958 (*Proceedings* V. 54), p. 1012.

2. Leber, I., and Blakey, F. A., "Some Effects of Carbon Dioxide on Mortars and Concrete," ACI JOURNAL, V. 28, No. 3, Sept. 1956 (*Proceedings* V. 53), pp. 295-308.

3. Steopoe, A., "The Effect of Carbon Dioxide on Hardened Cement," *Zement*, V. 24, 1935, pp. 795-797 (in German)

4. Lea, F. M., *The Chemistry of Cement and Concrete*, (revised Edition of Lea and Desch) St. Martin's Press, Inc., New York, 1956, p. 225; also p. 174 of 1935 Edition.

5. Moeller, Therald, *Inorganic Chemistry, An Advanced Textbook*, John Wiley and Sons, Inc., New York, 1952, p. 756.

6. Foret, Jeanne, "The Resistance of Tetracalcium Ferrite to Alkaline Agents and Carbonic Acid," *Comptes Rendus Hebdomadaires des Seances*, Academy of Sciences (Paris), V. 212, 1941, pp. 266-268 (in French); *Chemical Abstracts*, V. 37, 1943, p. 6576.

7. Johnston, John, and Williamson, E. D., "The Complete Solubility Curve of Calcium Carbonate," *Journal of the American Chemical Society*, V. 38, 1916, pp. 975-983.

8. Steinour, Harold H., "The System CaO-SiO_2-H_2O and the Hydration of the Calcium Silicates," *Chemical Reviews*, V. 40, 1947, pp. 391-460; reprinted as *Bulletin* 18, Portland Cement Association Research Department.

9. Steinour, Harold H., "Aqueous Cementitious Systems Containing Lime and Alumina," *Bulletin* 34, Portland Cement Association Research Department, Feb. 1951.

10. Eiger, A., Discussion, *Proceedings*, Symposium on the Chemistry of Cements, Stockholm, 1938, Ingeniorsvetenskapsakademien, pp. 173-174.

11. Johnston, John, "The Solubility-Product Constant of Calcium and Magnesium Carbonates," *Journal American Chemical Society*, V. 37, 1915, pp. 2001-2020.

12. Steinour, Harold H., Portland Cement Association, unpublished report, Apr. 1957.

Problems and Practices

A series relating to "down-to-earth, everyday" concrete problems which attempts to give brief answers to the more common (and sometimes uncommon, too) questions asked about concrete design and construction practices.

To some, the answers will seem simple and obvious; others may prove controversial.

All ACI members are invited to participate—either by submitting an inquiry, or even better, by telling JOURNAL readers how an intriguing problem was solved. It may well be that readers will be able to suggest more practical solutions than those presented.

Q. In Eq. (46) on p. 47 of "Specification for the Design and Construction of Reinforced Concrete Chimneys (ACI 505-54)" there is the difference of two expressions under the radical. In cases where f_{sw} *is considerably larger than* f_{STV} *the algebraic sum of the two expressions is less than zero, making the square root an imaginary number. In those cases, we have considered the square root to be zero. This not a particularly satisfactory solution because then* $f_{sw\text{-}comb}$ *is often smaller than the original* f_{sw}*, which, at least on the windward side, is improbable. Would you explain the use of the equation?*

A. The difficulty noted is due to using Eq. (46) for conditions where it is not required and not applicable.

Refer to Fig. 25, p. 46, and consider a chimney with temperature producing a maximum compression f'_{CTV} and tension f_{STV} and wind load just sufficient to balance the weight of the chimney so that there would be no tension in the reinforcing due to wind. Now as the wind load increases, temperature remaining constant, the compression due to temperature decreases to $f'_{sw\text{-}comb}$ as shown in Fig. 25. Let the wind load increase until $f'_{sw\text{-}comb}$ equals zero. When this condition is exceeded it is no longer necessary or proper to use Eq. (46) since now $f_{sw\text{-}comb}$ equals f_{sw}. This can easily be seen from the first steps in the derivation of Case 4 where the first resultant $pt\ f_{sw}$ equals the second resultant which, when $f'_{sw\text{-}comb}$ equals zero, is $pt\ f_{sw\text{-}comb}$.

The value at which $f'_{sw\text{-}comb}$ equals zero is easily determined since at this point k_{comb} equals zero. Solving Eq. (45) for k_{comb} equals zero we find

$$\frac{f_{sw}}{f_{STV}} = \frac{z}{z - k}$$

Consequently, for any specific chimney design it is a simple matter to determine the ratio f_{sw}/f_{STV}. If this ratio is less than $z/(z - k)$ use Eq. (46) to find $f_{sw\text{-}comb}$. Whenever f_{sw}/f_{STV} equals or exceeds $z/(z - k)$ it is unnecessary and incorrect to use Eq. (46) since $f_{sw\text{-}comb}$ equals f_{sw}.

In retrospect it would have been desirable to have stated this limitation with respect to the use of Eq. (46) in the standard. However, when the quantity under the radical becomes negative, it is a clear indication that this formula no longer applies. You will find that the ratio f_{sw}/f_{STV} will equal $z/(z - k)$ before the quantity under the radical becomes zero. To treat the value of the radical as zero, when it becomes imaginary, is definitely incorrect mathematically and in practice leads to smaller computed values of $f_{sw\text{-}comb}$ than the correct value f_{sw}. It is obvious from basic considerations that, on the windward side of the chimney, no combination of stresses due to temperature with stresses due to wind can produce less tension in the vertical reinforcement than the stress due to wind alone.

E. A. DOCKSTADER
Consulting Engineer
West Newton, Mass

CURRENT REVIEWS

of Significant Contributions in Foreign and Domestic Publications

Bridges

Recent highway bridgeworks in Glamorgan, with particular reference to prestressed concrete design and construction

EDWARD W. DAVIES, *Proceedings*, Institution of Civil Engineers (London), V. 7 (Session 1956-57), Aug. 1957, pp. 897-900

Reviewed by ARON L. MIRSKY

Brief extract from author's paper, discussing transverse versus longitudinal bending moments, loss of prestress, and vibration in prestressed concrete bridges.

Two recently completed reinforced concrete bridges (Zwei neuere Ausführungen von Stahlbetonbrücken)

HERMAN BAY, *Beton- und Stahlbetonbau* (Berlin), V. 52, No. 9, Sept. 1957, pp. 209-222

Reviewed by VALDIS LAPSINS

Describes two bridges of interesting design. One is a continuous, slightly curved reinforced concrete bridge, 107 m long and supported by round columns, with the longest span of 26 m. The other structure is a pedestrian bridge of 12-m rise which arches across a 90-m span between arch supports, with curved ramps extended in both directions.

Thin-slab prestress bridge

Pacific Road Builder and Engineering Review, V. 91, No. 2, Aug. 1958, pp. 8, 10, 50

HIGHWAY RESEARCH ABSTRACTS Nov. 1958

A prestressed concrete overpass bridge designed by the California State Division of Highways embodies many innovations. The advantages of the slender and symmetrical flat slab—only 18 in. thick and 117 ft long on the one example already constructed—permits bridge designers (a) to reduce the cost of approaches, or (b) to lessen the amount of roadway excavation necessary to provide proper clearance on the main line. Of importance to highway contractors is the fact that these bridges are cast in place, thus requiring scaffolding which limits use of the design on some projects.

Two prestressed concrete bridges at Lille—The Saint Agnes Bridge and the Fives Bridge (Deux Ponts en Béton Précontraint—Pont de Sainte Agnès et Pont de Fives)

W. KERN, *Construction* (Paris), V. 13, Jan. 1958, pp. 1-11; Feb. 1958, pp. 47-57; Mar. 1959, pp. 83-95

Reviewed by ALEXANDER M. TURITZIN

These bridges were built over the tracks at the approaches to a main railway station as a part of the new Paris-Lille highway. It was decided to use prestressed concrete which permitted use of precast sections. In this way, intricate scaffolds over the busy railroad tracks, required by cast-in-place concrete, were eliminated. Another advantage of using prestressed concrete was that a shallower deck for the same span and loading condition was obtained.

The Saint Agnes bridge is a five span bridge, 120 meters long, with two approach spans 17 meters long and three continuous spans 28, 35, and 23 meters long located over the main tracks. The Fives bridge is a three span continuous bridge with spans of 17, 30, and 21 meters. The two bridges had the same features and were designed using Guyon and Massonnet methods. The deck was made up of longitudinal girders in the form of wide flange beams placed side by side and tied together with concrete interstices, thus form-

A part of copyrighted JOURNAL OF THE AMERICAN CONCRETE INSTITUTE, V. 30, No. 8, Feb. 1959, (*Proceedings* V. 55.) Address P.O. Box 4754, Redford Station, Detroit 19, Mich. Where the English title only is given in a review, the book or article reviewed is in English. If it is followed by a foreign title the work reviewed is in that language. In those cases where the foreign title cannot conveniently be set in type or is not available, the language of the original article is indicated in parentheses following the English title. Copies of articles or books reviewed are **not** available through ACI. Available addresses of publishers are listed in the June "Current Reviews" each year. In most cases ACI can furnish addresses of publications added later.

For those members who cut apart this section for pasting on cards for card indexes, a limited number of complimentary reprints of the "Current Reviews" section are available from ACI headquarters on request.

ing a two way system of girders incased between top and bottom slabs. The longitudinal and transverse girders were prestressed with cables made up of 12 strands of 7 and 5 mm, respectively.

An interesting feature of the construction, was the erection of the central span in the three span continuous section. After the two end spans were erected, the central span was rolled over a temporary steel bridge erected over the middle section and lowered into final position. Continuity between the three precast spans was achieved with prestressing cables.

Author gives a sample computation of the bridge deck with numerous sketches showing typical reinforcing and a schematic erection procedure. He concludes with the discussion of the difficulties encountered during design and construction.

Design proposals for expressway bridge in Berlin (Wettbewerb füer die Brücke im Zuge des Nordwestbogens des Berliner Schnellstrassenringes)

HEINZ STILLER and GUENTHER JESKE, *Beton- und Stahlbetonbau* (Berlin), V. 53, No. 5, May 1958, pp. 106-117

Reviewed by VALDIS LAPSINS

Discusses ten design proposals submitted by various firms for the construction of a portion of circumferential expressway of Berlin, involving 875 m of bridge construction.

Construction

Problems in construction of dwelling house foundations (in Hebrew)

J. ELIAV, *In the Field of Building, Bulletin* No. 57, Israel Institute of Technology (Haifa), 1958, 14 pp.

The article deals with practical problems arising from small dimensions of house footings. The following aspects are discussed: continuous footings, pads, and column footings.

St. Rochus Church in Düsseldorf (Die St. Rochus-Kirche in Düsseldorf)

HEINRICH SCHMITZ, *Beton- und Stahlbetonbau* (Berlin), V. 52, No. 5, May 1957, pp. 97-104

Reviewed by VALDIS LAPSINS

New experiment in the construction of a unique reinforced concrete church tower and dome. The entire church structure basically consists of half circles built around a simple triangle. Total height of the structure is 28 m, with 7.2-m radius for each of the three half domes at the base. Design analysis as well as construction features are presented in the paper.

Quality tests of materials and their relation to construction costs (Über die zweckmaessigste Art der Güteprüfung und ihren Einfluss auf die Baukosten)

HUBERT RUSCH, *Beton- und Stahlbetonbau* (Berlin), V. 53, No. 3, Mar. 1958, pp. 56-60

Reviewed by VALDIS LAPSINS

Attempt made to establish specific relationship between construction costs and quality. No concrete formula is given although the main aspects of quality control are shown clearly.

Recent industrial buildings in reinforced concrete (Neuzeitliche Industriebauten in Stahlbeton)

HANS-JOACHIM EULITZ *VDI Zeitschrift*, (Düsseldorf), V. 100, No. 22, Aug. 1, 1958, pp. 1064-1068

Reviewed by ARON L. MIRSKY

Industrial buildings which are both functionally efficient and pleasant in appearance are the result of cooperation among process engineer, architect, and structural engineer, and concrete is being used more and more for such structures, particularly since the recent development of shell and prestressed types. Point is proved with descriptions and illustrations of several textile and plastics plants in North Rhine-Westphalia.

High speed building

International Civil Engineer and Contractor (London), V. 10, No. 5, Sept.-Oct. 1958, pp. 14-16

Reviewed by F. F. GAULD

A description of 11-story apartment blocks in Birkenhead, England with load bearing concrete wall built using sliding formwork. The Swedish "Prometo" system was employed to lift the formwork at a rate of up to 20 ft per 24 hr. Details of construction and placing methods are briefly covered.

Modern deck construction in the United States and in Germany (Neuzeitlicher Deckenbau in USA und Deutschland)

WILHELM WEISS, *Der Bauingenieur* (Berlin), V. 33, No. 2, Feb. 1958, pp. 41-50

Reviewed by ARON L. MIRSKY

Interesting article describing the many recent systems of deck construction developed

in this country and in Germany. Most of the American systems use concrete fill on steel plate-type members which act as both form and tension member of the composite deck (Corruform, Cellufloor, Q-deck, *et al.*); in Germany most of the recent systems use precast hollow fillers (concrete or ceramic) spanning between the truss-type reinforcement of the cast-in-place joists formed when the concrete topping is placed, while several other systems use precast reinforced plank, hollow or solid, with in-situ topping.

Construction of circulating-water pump house at Cowes Generating Station, Isle of Wight

RAYMOND H. COATES and LESLIE R. SLADE, *Proceedings*, Institution of Civil Engineers (London), V. 9. (Session 1957-58), Mar. 1958, pp. 217-232
Reviewed by ARON L. MIRSKY

Investigation after a cofferdam failure revealed a layer of fissured clay underlain by a thin stratum of sand containing water under a 35-ft head. Remedy was a concrete slab, cast under water and anchored to the underlying rock by prestressed cables.

Construction Techniques

Influence of amplitude and frequency in the compaction of concrete by table vibration

A. R. CUSENS, *Magazine of Concrete Research* (London), V. 10, No. 29, Aug. 1958, pp. 79-86
AUTHOR'S SUMMARY

Describes experimental work on the compaction of concrete by table vibration. The cases of castings of small depth and those of greater depth are separated and guiding principles suggested for each. The effects of rotational instability and the influence of the mold are considered.

Winter concreting practices (in Russian)

S. A. MIRONOW, *Novaja Tekhnika i Peredowoi Opyt w Stroitel'stve* (Moscow), No. 12, 1957, pp. 6-9
Reviewed by N. G. ZOLDNERS

Various winter concreting practices in USSR and the advantages of the different methods used are described.

The electric heating method, which produces hard concrete in 48 hours even in subzero weather, is most popular and widely used. The thermos method for mass concrete has proved more economical in milder weather conditions. Steam curing is recognized as the best method for quality concrete, but is economical only near a steam generating plant.

Most recently a widely used practice in winter concreting is the addition of some antifreeze chemicals (CaCl, NaCl, etc.), which keep the cement paste from freezing even at temperatures of −20 C.

The use of high-early-strength and aluminous cements in severe weather conditions is recommended. The best winter building practice mentioned in this paper is the increased use of precast concrete elements in construction work.

Machined finish applied to cellular concrete products (in Russian)

S. S. LEVIN, *Beton i Zhelezobeton* (Moscow), Aug. 1958, pp. 314-316
Reviewed by D. WATSTEIN

Machining in a milling machine was found to be one of the most effective methods of providing acceptable surface finishes to cellular concrete products. More than 70 such milling machines now operating in the Soviet Union are capable of handling slabs or panels up to 6.6 ft wide and 11.5 ft long. The depth of a cut may be as much as 0.8 in., if necessary.

Cutting edges are spaced around the circumference of a mill which rotates about a vertical axis, while the work is clamped to an advancing table. The spacing of the cutting edges and the speed of the work table determine the "fineness" of the finish, or the heights of the ridges left by the passage of the cutters. It is said that a surface having ridges about 0.01 in. high is quite acceptable and that these ridges are not visible at a distance of 6 ft. The machining operation is flexible and permits varying degrees of smoothness.

Tower-crane, type BK-5-248 (in Russian)

A. A. KALUPIN, *Novaja Tekhnika i Peredowoi Opyt w Stroitel'stve* (Moscow), No. 7, 1957, pp. 24-25
Reviewed by N. G. ZOLDNERS

Detailed description and drawing is given of the tower-crane, type BK-5-248, which is an improved model of an older version, type BK-5-195, and is designed for construction work of multistory buildings.

The crane is delivered to the building site with the tower dismantled in sections. It

can be set-up in three heights, for buildings ranging from three to nine stories. The crane moves along the structure on two rails, 5 m apart, and has a total weight of 38 tons at its full height. With the boom in horizontal position, a maximum 5-ton load can be lifted and handled into position in a radius of 22.7 m. Data on mechanical equipment and electrical motors are given only in general.

Introduction to concrete work, An

H. L. Childe, Concrete Publications, Ltd., London, 3rd Edition 1947, 126 pp., $0.80

An introduction to the principles and practice of concrete construction written primarily for students at technical schools in Great Britain. It describes in simple language the reasons for careful proportioning, the placing of steel in the correct position, the purpose of curing, and all other processes in the production of good concrete and reinforced concrete.

Portions of this book might be said to be similar to the *ACI Concrete Primer* and other portions similar to *ACI Manual of Concrete Inspection*.

Dams

Design and construction of Mauvoisin Dam (Le Barrage de Mauvoisin son exécution et ses installations de chantier)

M. P. Colomb, Supplement to *Annales de L'Institut Technique du Batiment et des Travaux Publics* (Paris), No. 126, June 1958, Series Travaux Publics (51), pp. 804-822

Mauvoisin Dam, located at the bottom of a V-shaped gorge on the Rhone river in Switzerland, measures 777 ft in height, has a retaining capacity of 236 million cu yd, permitting an annual production of 760 million of kwh. For design, the arch dam was regarded as a juxtaposition of vertical walls and horizontal arches. Mass concrete, proportioning of which varied for different parts of the dam, was placed in large sections, and the heat generated by hydration was compensated by a refrigerated water circulating system running through 217 miles of pipe.

The work of construction is described in detail and includes 1,960,000 cu yd of excavation and the placing of 2,600,000 cu yd of concrete in 4 years. The solutions of the various technical problems which arose in connection with materials supplies, setting up the job site installation, protection against landslides and the human conditions connected with work at high altitudes are also given attention.

Dam construction in Switzerland (Über den Bau der Talsperren in der Schweiz)

J. P. Stucky, *Zement-Kalk-Gips* (Wiesbaden), V. 10, No. 11 and 12, Nov. and Dec. 1957, pp. 453-461 and 500-503

Reviewed by H. H. Werner

This is an interesting and up-to-date résumé of dam construction in Switzerland, describing: design factors; technology of concrete aggregates, mixes, curing, etc.; mechanization of site installations and placing of concrete. A new concept of permissible stresses and factors of safety is developed, based on material selection, industrialized methods, constant quality control, and use of big test specimens (30 cm diameter, 45 cm high).

Design

Analysis of temperature stresses in ring shaped girders supporting tanks with warm liquids (in Rumanian)

Einar Keintzel, *Revista Constructiilor si a Materialelor de Constructii* (Bucharest), V. 10, No. 1, 1958, pp. 25-28

Reviewed by J. J. Polivka

Structural analysis of circular girders with constant and variable cross section, to be used also for concrete bins.

Iteration method of analyzing continuous beams and frames with undisplaced joints (in German)

M. Todorow, *Bautechnik* (Berlin), V. 35, No. 1, Jan. 1958, pp. 21-22

Reviewed by J. J. Polivka

New type of moment distribution method of continuous beams without elastic supports and frames without lateral swaying is presented and clarified by numerical examples. Although theoretically correct, this and all similar methods using the principle of moment distribution have the disadvantage of less accuracy which depends on the number of iterations. Prime disadvantage of these methods can be expressed by two facts: (1) Accuracy of the results can be checked only

after all calculations are completed. If errors are found, the whole analysis must be repeated from the beginning. (2) These types of structures are usually designed for several most unfavorable loading conditions, and the calculations of all moment distribution methods (structural analysis) must be repeated for every different loading. Other methods of analysis can be checked at each stage of calculation, and basic factors of analysis are determined right at the beginning and are valid for any type of loading.

Analysis of temperature stresses in ring-shaped girders supporting tanks with warm liquids (in Rumanian)

EINAR KEINTZEL, *Revista Constructiilor si a Materialelor de Constructii* (Bucharest), V. 10, No. 1, 1958, pp. 25-28

Reviewed by J. J. POLIVKA

Structural analysis of circular girders with constant and variable cross section. Also adaptable to concrete bins.

Carrying capacity of materials subjected to nonmultiple repeated loadings (in Russian)

I. L. KORCHINSKII, *Bulletin Stroitelnoi Tekhniki* (Moscow), V. 15, No. 3, Mar. 1958, pp. 19-22

Reviewed by HERBERT E. KEBE

Brief article presents mathematical derivations for stress computation for several building materials in case of dynamic loading particularly when those loadings are nonmultiple, as in seismic occurences. Suggests use of coefficient for different kinds of building materials, and gives their values for steel, reinforced concrete, and wood structures.

A structural simulator—for static analyses

FREDERICK L. RYDER, *Consulting Engineer*, V. 10, No. 6, June 1958, pp. 84-90

Reviewed by ARON L. MIRSKY

Advantages of structural simulators, as compared to conventional analog computers, are stressed. Principles of the simulator are discussed and applied to various types of members and structures. A demonstration apparatus is briefly described.

Paper merits reading. A companion paper, giving data on time needed for setting up and solving several actual problems, by both experienced and inexperienced personnel, would be of interest and value.

Circular plates of reinforced concrete (in Dutch)

J. WITTEVEEN, *Polytechnisch Tijdschrift* (The Hague), V. 13, No. 31-32, July 31, 1958, pp. 559-561

Reviewed by JOHN B. SNETHLAGE

The author develops practical formulas and graphs for bending moments in circular plates for various kinds of annular support.

Moments at the center of elastic plates due to uniformly distributed loads

D. ZLOKOVIC, *Naše Graderinarstvo* (Belgrade), V. 12, No. 1, Jan. 1958, pp. 34-40

Reviewed by J. J. POLIVKA

Presented analysis and tabulated values refer especially to reinforced concrete slabs of rectangular shape freely supported at the periphery and restrained along various edges, considering load concentration at the center.

Plastic design in reinforced concrete

W. T. MARSHALL, *The Structural Engineer* (London), V. 35, No. 7, July 1957, pp. 243-251

Reviewed by C. P. SIESS

Presents elementary discussion of plastic design and methods of calculating ultimate strengths and permissible hinge rotations, and gives design examples for simply supported beams, columns, continuous beams, and portal frames. Reviews test data on continuous beams, portal frames, and arches as vertfication of plastic theory.

Composite construction in steel and concrete: for bridges and buildings

IVAN M. VIEST, R. S. FOUNTAIN, and R. C. SINGLETON, McGraw-Hill Book Co., Inc., New York, 1958, 192 pp., $7.50

Explaining composite construction, this manual develops design equations and procedures and describes methods of connecting slabs to beams. It presents tables and charts for preliminary designs. Because composite bridges are more common than composite construction for buildings, more emphasis is placed on bridge design.

For the designer not experienced in composite design it contains explanations of the basic principles and several design examples. The reader is, however, assumed to be familiar with ordinary design of concrete slabs and steel beams.

Methods are given for selecting the cross section of a composite beam. Two design methods are presented—one limited to beams

with rolled steel sections and the other applicable not only to these beams but also to rolled steel sections with cover plates and to built-up plate girders. A rapid method for the design of composite beams is presented in detail and illustrated by six examples. Special problems are covered, such as the determination of the length of cover plates, design of continuous beams, and computation of deflections. Design methods are presented for the three most commonly used shear connectors: studs, flexible channels, and spirals.

Successive approximations applied to the design of walls of circular reinforced concrete tanks

R. J. Miersch, *Journal*, Institution of Engineers, Australia (Sydney), V. 30, No. 10-11, Oct.-Nov. 1958, pp. 299-307

Author's Summary

The method of tank wall analysis demonstrated gives a safe solution for all foundation types insofar as they affect the lateral deflection at the base of the wall. The method takes into account all major variables and the solution permits controlled cracking.

The arithmetic involved is a disadvantage of the method. It should, however, be possible to build up families of curves from which the wall dimensions and reinforcement could be selected for any particular tank. Such standardization would require the analysis of a large number of tanks in which the capacity and h/d are varied independently.

Results of tests and theory of calculations of rigid self-supporting vaults (Résultats d'essais et théorie de calcul des voutes autoportantes rigides)

J. Barets, Supplement to *Annales de l'Institut Technique du Batiment et des Travaux Publics* (Paris), No. 122, Feb. 1958, pp. 142-177

Reviewed by Edmund A. Pratt

This paper reviews briefly the historical aspects of reinforced concrete arched vaulting and discusses the materials employed and the design hypotheses. A general discussion on the design calculations of self-supporting rigid vaults follows. Parabolic arch rings and parabolic vaults are considered, and the various solutions are compared. The author's method of calculation is presented. The paper describes a load test on a scale model (approximately 1/5 size) of arched vaulting supporting a suspended floor system with unsymmetrical loading. Results of the test are discussed in detail. Test results verify the author's method as applied to transversely rigid self-supporting vaults.

Design criteria for embedment of piers

E. Czerniak, *Consulting Engineer*, V. 10, No. 3, Mar. 1958, pp. 90-95

Reviewed by Aron L. Mirsky

Presents formulas and design charts for embedment, shear, and moments in piers (drilled piles). Worked examples are included. Material will be of considerable use to practicing engineers.

Prestressing analysis of closed reinforced concrete water reservoirs (Zur Berechnung der Vorspannung geschlossener Kreiszylinderschalen im Stahlbeton-Behälterbau)

Karl Buyer, *Beton- und Stahlbetonbau* (Berlin), V. 52, No. 5, May 1957, pp. 104-111

Reviewed by Valdis Lapsins

Analysis and basic design principles of prestressing of closed tanks under symmetrical loading presented with practical design examples and application in the field.

Determination of fixed-end moments for prismatic members

J. C. Steedman, *Concrete and Constructional Engineering* (London), V. 53, No. 9, Sept. 1958, pp. 321-326

Charts are given for the determination of fixed-end moments caused by partial uniform or triangular loads. Moments are given in the form of a coefficient times span times total load on the span. Values for most combinations of loads can be obtained by superposition and the position of a partial uniform or triangular load which causes the greatest possible fixing moment can also be obtained.

Design of reinforced concrete

Carl Forssell, *Transactions*, Royal Institute of Technology, Stockholm, No. 117, 1957

Reviewed by Margaret Corbin

Pamphlet presents charts for the design of reinforced concrete sections subjected to bending based on the ultimate strength theory. The analytical results were verified in tests of 22 beams with 0.4 to 3.4 percent reinforcement and a concrete cube strength from 125 to 400 kg/sq cm. Close agreement was established between theoretical and experimental results.

Materials

Rubber waterstops

P. L. CRITCHELL, *International Civil Engineer and Contractor* (London), V. 10 No. 5 Sept.-Oct. 1958, pp. 23-24

Reviewed by F. F. GAULD

A brief account of strength and aging tests carried out in France on 9-in. and 6-in. dumbbell type rubber waterstops only. Water pressure tests are noted but are noncyclic with no note of leakage.

Determination of the specific gravity of building materials (Die Bestimmung der Reinwichte von Baustoffen)

K. WESCHE and J. STEPATH, *Zement-Kalk-Gips* (Wiesbaden), V. 10, No. 10, Oct. 1957, pp. 418-421

AUTHOR'S SUMMARY

A gravimetric method for determining specific gravity of building materials is described which is characterized by its high degree of accuracy and the small amount of time required. The method is particularly suitable in cases where series of determinations have to be carried out as, for instance, frequently occurs in the investigation of cements and concretes.

Expansive cements (in Japanese)

TARO TANAKA and YOSHIKA WATANABE, *Semento Gijutsu Nenpo*, V. 8, 1954, pp. 192-202

CERAMIC ABSTRACTS Oct. 1958 (Y. Suzukawa)

To determine the mixing proportions of a commercial expansive cement, centrifugal separation was made with liquids of high specific gravity at 3000 rpm. The results indicate that the expansive cement consists of 65 parts (by weight) portland cement, sulfoaluminate clinker 25 parts, and 10 parts blast furnace slag of $(CaO + Al_2O_3 + MgO)/SiO_2 = 2.11$. Sulfoaluminate clinkers were prepared by burning mixtures of natural gypsum, bauxite, limestone, and pyrite cinder at 1300 to 1350 C. The effects of the chemical compositions of the sulfoaluminate clinkers prepared on the linear expansion of neat cement paste were tested. Expansive cements were prepared by mixing commercial portland cement 70 parts, commercial or synthetic slag 10 parts, and the sulfoalaluminate clinker 20 parts by weight. Compressive strength and linear expansion of the expansive cements prepared are shown.

Presetting cracks in fluid concrete

F. D. BERESFORD and E. N. MATTISON, *Constructional Review* (Sydney), V. 31, No. 9, Sept. 1958, pp. 23-26, 33-36

Reports a limited investigation of plastic shrinkage of laboratory-mixed concretes of high workability containing one brand of Australian cement. Cracking over reinforcement was found to be correlated with the form of the settlement curve and could be predicted from settlement rate, total time of settlement, and depth of reinforcement.

Rapid drying conditions resulted in more severe cracking. A higher proportion of coarse aggregate, a nonionic air entraining agent, tended to reduce cracks over reinforcement.

Alkali Content of Danish Cements; A new Danish alkali-resistant cement; Methods for the determination of alkalies in aggregate and concrete

ERIK V. MEYER (Reports 1 and 2); J. ANDERSEN and L. DITLEVSEN (Report 3); *Progress Report* No. F 1, 2, and 3; Committee on Alkali Reactions in Concrete, Danish National Institute of Building Research and Academy of Technical Sciences, Copenhagen, 1958, 21 pp., 12 D. kr. (25 percent discount may be obtained by ordering the whole series)

Three more reports in the continuing series issued by the Committee on Alkali Reactions in Concrete. The first paper presents data on the alkali contents in Danish cements; the second paper describes the new Danish low alkali cement. It is of interest to note that this cement is not only low in alkali content but also contains pozzolan for general prevention of alkali reactions. The third paper describes methods used in the laboratory for determination of alkalies in aggregates and concrete.

Quantitative spectroscopic determination of the principal components of minerals in the cement industry (Die quantitative spektro-chemische Bestimmung der Hauptkomponenten von Mineralien der Zementindustrie)

V. R. PFEUNDER and H. SCHWANDER, *Zement-Kalk-Gips* (Wiesbaden), V. 10, No. 10, Oct. 1957, pp. 394-398

AUTHOR'S SUMMARY

A method has been developed which permits the principal components of the cement raw materials and of the cement clinker to be determined quantitatively by relatively simple spectrum analysis. It is shown that

the results are equivalent to those by the gravimetric method and have a lower standard deviation. Only one spectroscopic exposure is required for the determination of CaO, SiO_2, Fe_2O_3, and Al_2O_3. The time taken up by a complete analysis is about 2 hr.

Hydraulic cement for water tanks and pipe lines

W. C. HANSEN, *ASTM Bulletin*, No. 232, Sept. 1958, pp. 51-54

AUTHOR'S SUMMARY

Studies were made with mortars of three samples of Type I portland cement and three samples of Type IS portland-blast-furnace slag cement to demonstrate the rates at which CaO, Na_2O, and K_2O would be leached from water-carrying pipe lines and water tanks lined with concrete made with these cements. The results of the study show a slight superiority for Type IS cement over Type I cement for this type of service.

Staining of concrete by pyrite

H. G. MIDGLEY, *Magazine of Concrete Research* (London), V. 10, No. 29, Aug. 1958, pp. 75-78

AUTHOR'S SUMMARY

Concretes and mortars made with some Thames River gravels have, in recent years, been suffering from brown staining. This has been traced to the mineral pyrite, FeS_2. Not all specimens of the mineral are reactive and it is possible to distinguish between the reactive and unreactive by a simple test. On immersion of the suspect pebble or grain in lime water, the reactive forms will produce a brown precipitate within a few minutes while the unreactive form is stable.

Effects of the properties of coarse aggregates on the workability of concrete

M. F. KAPLAN, *Magazine of Concrete Research* (London), V. 10, No. 29, Aug. 1958, pp. 63-74

AUTHOR'S SUMMARY

Thirteen coarse aggregates were investigated to determine the effects of their shape, surface texture, and water absorptive capacity on the workability of concrete. An attempt has also been made to assess these effects quantitatively.

The main conclusions were:

1. Changes in the angularity of coarse aggregates have a greater effect on the workability of concrete than changes in the flakiness of the aggregates. Increased angularity and/or flakiness leads to a reduction in the workability of concrete.

2. Although there was a wide variation in the surface textures of the aggregates, no correlation was found between this property and the workability of concrete.

3. The differences in absorption capacity were insufficient to produce significant changes in the compacting factor. No correlation was, therefore, found between this property and concrete workability. This does not rule out the possibility that highly porous aggregates when used dry will affect the workability of concrete.

Determination of pozzolanic activity of fly ash through a weathering test (in French)

J. Y. KARPINSKI, *Revue des Matériaux de Construction et de Travaux Publics* (Paris), No. 510, Mar. 1958, pp. 63-73

Reviewed by PHILLIP L. MELVILLE

Standard test specimens were made and wet cured with a constant W/C to determine the optimum amount of pozzolan (in form of fly ash). In a second series of tests, the optimum amount of pozzolan was used and the mixing water varied. Results are evaluated from the weight changes after cycles of wetting (in sodium sulfate solution) and air drying.

Contribution to the study of the volume stability of cements (Beitrag zum Studium der Volumenbeständigkeit der Zemente)

G. GOGGI, *Zement-Kalk-Gips* (Wiesbaden), V. 11, No. 9, Sept. 1958, pp. 383-392

Reviewed by H. H. WERNER

Expansion phenomena occurring in autoclave tests are investigated and found to be attributable to: (a) the potential C_3A content; (b) the behavior of clinker in cooling, i.e., vitreous or crystalline; and (c) the fineness of the clinker.

Furthermore, a marked difference between results of autoclave tests and prolonged storage in water was observed. Autoclave tests appear to be reliable only where fairly large amounts of free lime and MgO are involved, but do not seem to provide a sound criteria for normal cements if a long-term estimate of their volume stability is required.

Alkali reactions in concrete aggregates (in German)

R. A. J. Bosschart, *Zement-Kalk Gips* (Wiesbaden), V. 11, No. 3, 1958, pp. 100-108
Ceramic Abstracts Oct. 1958 (M. Hartenheim)

An investigation of cracked concrete units in Holland showed that cracks occurred only on wetting the concrete. The cracks were therefore attributed not to shrinkage but to swelling. The cause was traced to the reaction of the reactive silica of the aggregates with the alkali of the cement. The gravels used contain flint, which may be a form of silica sensitive to alkali. The best method of preventing expansion is to add finely ground reactive silica; the use of a cement with a low alkali content does not solve the problem. A slight alkali reaction need not be harmful and may even compensate for the shrinkage of the cement.

Chemical reactions involved in the hardening of cement (Die chemischen Reactionen bei der Zementerhärtung)

H. zur Strassen, *Zement-Kalk-Gips* (Wiesbaden), V. 11, No. 4, Apr. 1958, pp. 137-143
Reviewed by H. H. Werner

Describes an investigation regarding the formation of complex hydrates which simultaneously contain lime, alumina, and silica or alternatively lime, alumina, iron oxide, and silica. Production was possible only of "gehlenite hydrate" and mixed crystal series of "hydrogarnets," but not the compounds C_4ASH_{13} and $C_6AS_2H_{31}$. It was found that a terminal member of the hydrogarnets, C_3FH_6, does not exist.

Formation conditions and behavior of these hydrates are investigated and inferences drawn regarding the resistance of binding agents to attack by sulfate solutions.

Mortars for cold weather work (in Russian)

D. M. Levanow, *Novaja Tekhnika i Peredowoi Opyd w Stroitel'stve* (Moscow), No. 9, 1957, pp. 1-4
Reviewed by N. G. Zoldners

Brick buildings in the USSR are usually finished by exterior mortar rendering. Protection of plastering work in winter by speeding up the mortar setting time is discussed. Conventional methods such as use of high-early-strength cements, the reduction of W/C, the use of fatter mixtures, heating of the mortar ingredients, use of finely ground unhydrated lime, or the addition of chemical accelerators might not be effective enough.

A highly efficient accelerator for cold weather plastering work is mixed cement. Addition of up to 30 percent of aluminous cement to the standard portland cement produces an effective binder, which permits the use of cement mortars at near-freezing temperatures. The right proportion of the mixture has to be determined separately in each case for different cements and air temperatures. If sufficient control is available on the job site a desired fast set and rapid hardening of mortar can be achieved.

Pavements

Design of concrete roads in some European countries

F. N. Sparkes, *Roads and Road Construction* (London), V. 36, No. 426, June 1958, pp. 175-184

A summary of practices in Belgium, Denmark, France, Germany, Great Britain, Netherlands, and Sweden. The summary covers bases, concrete slab design, concrete, and joint spacing.

The summary shows the widely different views held on many features of design. For example, the spacing of expansion joints varied between 10 and 80 m; in some areas, expansion joints were dispensed with altogether. Other differences included the spacing of contraction joints, amount of reinforcement, nature and thickness of the base, mix proportions and workability of concrete, methods of construction, and design of joints.

Incipient coefficients as criteria of pavement grip (Kraftschlussbeiwerte als Kennzeichen der Strassengriffigkeit)

Karl Croce and Hermann Schmitz, *VDI Zeitschrift* (Düsseldorf), V. 100, No. 7, Mar. 1, 1958, pp. 280-285
Reviewed by Aron L. Mirsky

Discussion of methods and results of measurements of slipperiness and skid resistance of various pavements.*

*For a recent usage of the term "incipient coefficient" see "Measurement of Pavement Skidding Resistance by Means of a Simple 2-Wheel Trailer," P. C. Skeels, *Bulletin* No. 186, Highway Research Board, Sept. 1958, pp. 35-45.

Reinforcement in continuous concrete pavements

VEDAT A. YERLICI, *Proceedings*, ASCE, V. 84, HW 3, Oct. 1958, pp. 1799-1–1799-8

AUTHOR'S SUMMARY

Presents a reinforcement design procedure for continuously reinforced concrete highway pavements. On selection of a maximum permissible crack width, a section of the slab between cracks is analyzed to satisfy the static equilibrium and the assumed geometric condition that the slab length does not change. Formulas are derived for necessary crack spacing and optimum steel area and perimeter.

Experimental prestressed concrete highway project in Pittsburgh

BEN MORRELL, JOHN J. MURRAY, and JOHN E. HEINZERLING, *Proceedings*, Highway Research Board, V. 37, 1958, pp. 150-193

Describes construction of 530-ft experimental prestressed concrete pavement, 5 in. thick, at Pittsburgh. Gap jacking at the center of the slab was used; a frame held the gap open while it was being concreted. A special laminated steel and rubber expansion joint rests on a long, flexible sill. Limited static and moving load tests are reported.

Authors conclude that longitudinally reinforced prestressed concrete highway pavement is practical and structurally sound. Application of mass production techniques should make it competitive with reinforced concrete pavements. Joint system used appears promising.

Pavement performance—methods for evaluation

Bulletin No. 187, Highway Research Board, Sept. 1958, 78 pp., $1.60

The several papers and discussions published in this bulletin bring together much of the information that is known about identifying and explaining all kinds of defects and failures in paved highways.

"Types and Causes of Failure" gives charts outlining classification of failures for bituminous road surfaces and for portland cement concrete pavements. Excellent photographs aid in describing various kinds and stages of pavement distress.

The second paper deals with warning signs of distress in airport pavements as viewed by the U. S. Civil Aeronautics Administration. It tells of investigations that showed relationships of service behavior to the theoretical concepts in design of the pavements and to the results of accelerated traffic tests.

A paper from the Corps of Engineers reports on some historic investigations that included evaluation of rigid pavement performance and failure criteria for flexible pavements.

From the Bureau of Public Roads, a paper summarizes briefly what was learned about a 9 year old concrete pavement by subjecting it to controlled full legal truck operations.

Appropriate elements for rating a pavement are discussed in another paper and the last paper describes the methods and some of the results of a pavement performance inventory in Michigan.

Prestressed Concrete

Is prestressed concrete really more expensive than the classical reinforced concrete? (in Croatian-Serbian)

E. BALGAC, *Naše Graderinarstvo* (Belgrade), V. 12: Part 1, No. 2, Feb. 1958, pp. 40-48; Part 2, No. 3, Mar. 1958, pp. 61-71; Part 3, No. 4, Apr. 1958, pp. 84-90

Reviewed by J. J. POLIVKA

On the basis of thorough calculations and investigations of costs of various systems and construction methods it is proved that even in Yugoslavia, still lacking in recent equipment and under consideration of expensive high-tensile steel, the costs of typical prestressed concrete structural members are 8-24 percent less than such in ordinary concrete, which saving increases close to 50 percent for girders spanning over 40 m (130 ft) Investigations are made for various cross sections, as of rectangular, T-, and I- shapes. Various methods of prestressing are also considered.

Prestressed concrete water tower in Orebro, Sweden

KURT ERIKSSON, *Civil Engineering*, V. 28, No. 10, Oct. 1958, pp. 68-73

Prestressed concrete water tower combines elegance with utility. Total height above foundation is 223 ft and maximum diameter is about 150 ft. The reservoir, with a capacity of 2,400,000 gal., is sup-

ported by a cylindrical stem. The outer reservoir wall, which is prestressed horizontally, is conical with a slope of 1 vertical to 1.5 horizontal. The outer surface is polygonal with 32 faces.

Scaffolding for the reservoir was a major construction problem because of its height and shape. The contractor avoided tall scaffolding and facilitated placing of the concrete by constructing the reservoir on the ground. After it had been cast, prestressed, tested, and painted, the reservoir was lifted to its final position 115 ft above the ground by hydraulic jacks. The cylindrical stem was cast simultaneously with the lifting process using sliding forms.

Lifting was terminated in such a way that the reservoir can be raised further in the future if required. Altogether a rather unique structure where some unusual construction and prestressing techniques were used.

PCI standards for prestressed concrete plants (tentative)

PCI Plant Standards Committee, *Journal*, Prestressed Concrete Institute, V. 3, No. 2, Sept. 1958, pp. 36-45

The objective of these regulations is to establish a minimum standard for prestressed precast concrete manufacturing plants. The standard covers materials used, plant equipment, personnel, and central casting yard manufacturing techniques.

Prestressed concrete water tower at Orebro, Sweden (Chateau d'Eau a Orebro, Suede)

M. Kurt Eriksson, *Construction* (Paris), V. 13, No. 5, May 1958, pp. 145-148

Reviewed by Alexander M. Turitzin

The form of a morning glory with a long cylindrical stem was chosen for a 9000 cu m capacity water tower, built in the center of the city. Because of its large capacity, and height of about 50 m above ground, the project of building a conventional reservoir supported on cylindrical wall or posts was abandoned. Prestressed concrete made it possible to design a slender structure with a stem of 10.5 m in diameter topped by a reservoir of a maximum diameter of 46 m. The thickness of the reservoir walls varied from 3 cm at the top to 6 cm at the bottom. It was prestressed with cables of twelve 7 mm strands with an elastic limit of 125 kg per sq mm and a breaking point of 150 kg per sq mm. In figuring the loss of prestress, German specifications DIN 4227 was used. The Freyssinet method of prestressing was employed.

A restaurant, and a radio and television room were built on top the reservoir with an elevator shaft running inside the cylindrical stem. The bottom of the stem was set in rock about 10 m below ground where utility rooms are located.

To avoid a possible loss of water, it was decided to cast the slender reservoir walls without joints in a single operation using a slow setting cement. Also to minimize the formation of cracks through the deformation of forms placed on high scaffolds, it was decided to cast the reservoir on the ground. It was gradually raised by jacks to its final position during the casting of the cylindrical stem. It was found that prestressed concrete permitted the creation of a new slender form of concrete water tower at a cost not higher than that of conventional construction.

Tests of steel for prestressed concrete (Résultats d'une série d'expériences sur aciers pour beton precontraint)

Franco Levi, *Proceedings*, Second Congress of Fédération Internationale de la Précontrainte, Amsterdam, 1958 (published 1958), pp. 137-155

A résumé of the results of tests on high tensile steel for prestressing. The main results refer to the characteristics of the stress-strain diagram, relaxation, brittleness, and fatigue resistance.

Failure of simply supported prestressed beams: role of grout and anchorage in behavior at failure (Essais de rupture de poutres précontraintes isostatiques: rôle de l'injection et des ancrages dans le comportement à la rupture)

Ugo Rossetti, *Proceedings*, Second Congress of Fèdération Internationale de la Précontrainte, Amsterdam, 1955, (published 1958), pp. 40-52

Reports a series of tests on simply supported prestressed beams of different types. Experimental results are compared with values calculated according to methods proposed by various authors. The effect on the value of the ultimate moment was determined

for the following factors: inside or outside fixing of cables; bonded or unbonded inside cables; outside cables fastened to the inside by means of stirrups or merely coated with mortar; and monolithic or precast unit construction.

Properties of Concrete

Electronics determines cement setting time

J. M. Tobio, *Electronics*, V. 31, No. 41, Oct. 10, 1958, pp. 88-90

Reviewed by Aron L. Mirsky

Describes simple test wherein sample of cement paste is inserted in a cylindrical (cell tube) capacitor, where it functions as a dielectric. Admittance of sample is measured and recorded every 15 min (continuously, if automatic recording is used); maximum reading corresponds to end of setting process. Close correlation is shown between results of this test and standard Vicat needle or mechanical (energy used in cutting groove in paste) tests. Electronic equipment is described.

Creep of concrete

Torben C. Hansen, *Bulletin* No. 33, Swedish Cement and Concrete Research Institute at the Royal Institute of Technology, Stockholm, 1958, 48 pp.

Author's Summary

A critical discussion on some important problems concerning the creep of concrete, and presentation of a new aspect of creep and the interpretation of creep tests.

The first chapter deals with the definition of creep and the usual method of measuring creep. It is concluded that the most common method of measuring creep, where shrinkage is taken into account by measuring simultaneous shrinkage of unloaded companion specimens, cannot always be used successfully.

In the second chapter various theories of creep and shrinkage are critically reviewed. It is concluded that either the shrinkage or the moisture diffusion has a severe influence on the capacity for creep of concrete.

The concept of "basic creep" is introduced in chapter three. Basic creep is defined as creep when no moisture diffusion takes place in the concrete while loaded. It is asserted that any empirical connection between basic creep and the different factors that influence creep can be directly analyzed in a theoretical way, by means of volumetrical or rheological considerations, since the results obtained from experiments have not been distorted by the different effects of drying or wetting on the various concretes.

In chapter four it is established that concrete at normal working load is fluid viscoelastic. On this assumption a formula relating the modulus of elasticity of concrete to the modulus of elasticity of the components has been set forth. This formula is in good agreement with experimental results.

It is shown that the principal of superposition of time effects is valid for concrete.

Finally, it is stated that the long-time deformation of a fluid viscoelastic material like concrete has no theoretical limit value with time.

In chapter five a short explanation of the mechanism of creep in concrete is given. A theoretical formula is derived relating creep to the volume concentration of cement paste in concrete and to the water-cement ratio by solid volume. It is shown that this formula is in agreement in the main with experimental results.

In connection with chapter five, a rheological model of concrete based on theoretical considerations is suggested. Experiments have shown that the behavior of this model is in good agreement with the rheological behavior of concrete.

Evaluation of alkali reactions in concrete by the chemical test

K. E. Haulund Christensen, *Progress Report* H 1, Committee on Alkali Reactions in Concrete, Danish National Institute of Building Research and Academy of Technical Sciences, Copenhagen, 1958, 58 pp., 12 D. Kr. (A 25 percent discount may be obtained by ordering the whole series)

Describes the "chemical test" developed by Mielenz, *et al.*, in 1947 and reports on the investigations of 152 samples of aggregates by this method. The aggregates were also investigated by the mortar bar test thus making a direct comparison of both methods possible.

Different classification by the two methods was found for 22 percent of the samples. (To a certain extent this might have been due to inaccuracies of the mortar bar test.) Certain modifications of the chemical test were investigated and it is indicated that the suggested modifications in the procedure simplify the testing.

Concrete for special purposes in the USSR (Špecialny betóny v SSSR)

B. G. Skramtajev (Skramtaev), *Stavebnícky Časopis Slovenská Akadémia Vied* (Btatislava), V. 6, No. 3, June 1958, pp. 131-137

Reviewed by J. Stork

The paper read at a Czechoslovak-Polish conference on concrete technology in 1957, presents an outline of technology of high grade concretes made in the USSR especially for prestressed concrete structures. It deals with various questions such as: portland cement activation; proportioning of concrete mix; methods of compaction of fresh concrete; curing of concrete; as well as with various aspects of concrete for special purposes such as hydraulic structures, fire-resistant concrete, lightweight concrete, etc.

Determination of homogeneity of concrete (Zjišťování stejnorodosti betonu)

M. Vorlicek, *Stavebnícky Časopis Slovenská Akadémia Vied* (Bratislava), V. 6, No. 3, June 1958, pp. 185-194

Reviewed by J. Stork

To determine the homogeneity of concrete it is necessary to know the distribution of strength to be found by statistical methods. Author presents his attempt to derive the frequency curve taking into account the various factors affecting strength of concrete. This frequency curve is represented closely by Pearson's curve of the third type. The results of the analysis may be applied directly on the site to determine the homogeneity of concrete.

Application of the theory of creep (in French)

N. Kh. Aroutiounian, Editions Eyrolles, Paris, 1957, 319 pp., 4765 F

Reviewed by A. W. Coutris

This book, translated into French from Russian, constitutes the first attempt at a systematic and more generalized treatment of concrete creep and its implications for design practice. It contains eight chapters. The first two chapters establish the basic integral equations governing the equilibrium of an elasto-plastic medium and relating arbitrary stress and strain. Age and past stress-strain history of the material are appropriately accounted for by the introduction of the variable of time. The next five chapters deal with practical applications of the general theory to specific creep problems connected with concrete, reinforced concrete, and prestressed concrete construction, such as (1) thermal stresses in mass concrete, (2) stresses due to shrinkage, (3) settlement stresses with consideration of creep, (4) state of stress in bent and compressed reinforced concrete elements, (5) shrinkage stresses in reinforced concrete pipes, (6) reinforced concrete frames, and (7) stress losses in prestressed beams and pipes due to creep and shrinkage of concrete. The final chapter is devoted to the basic stress-strain integral equations in the case of a nonlinear relationship between creep and corresponding stresses and the solution of some simple problems. Though the book requires a moderate degree of mathematical maturity to be read easily, the author has thrown back the solution of the integral equations to the solution of linear differential equations with variable coefficients, a familiar mathematical topic for most engineers. The book certainly is one which should be examined by every engineer, both those just wishing to learn more about the behavior of concrete structures and those concerned directly with the influence of creep in the computation of stresses.

Study to make concrete resistant against aggressive action of seawater

Leo Babic, *Naše Graderinarstvo* (Belgrade) V. 11, No. 8, Aug. 1957, pp. 205-209

Reviewed by J. J. Polivka

First a thorough chemical analysis of both concrete and seawater is necessary. Resistance was investigated under various conditions and for different composition and properties of concrete, especially granulometric mixture of gravel and sand, admixture of pozzolanic cement for greater impermeability, water-cement ratio, and natural humidity of aggregates. Study and research were made for Rijeka project.

Current study of creep in concrete

J. R. Keeton, *Budocks Technical Digest*, No. 88, July 1958, p. 10

Highway Research Abstracts Nov. 1958

In pilot studies, described in this letter report, cylinders 3 x 9 in., 4 x 12 in., and 6 x 18 in. were loaded after 7 days curing and at 28 days, employing stresses of 1100, 2200, and 3300 psi. Duplicate sets of specimens were

placed in 20 percent and at 50 percent relative humidity environments. Electronic strain-measuring devices were compared with mechanical strain-measuring devices.

The tests showed that: the net creep in concrete (total deformation minus instantaneous elastic deformation and minus shrinkage deformation) is approximately the same, both for the electronic and mechanical methods of deformation measurements; however, many more cycles of electronic measurements can be made, compared to mechanical measurements, in a short time; creep of concrete, other factors being equal, decreases as the volume of the specimen increases; 50 percent of total deformation occurring in 2 months took place in the first 2 days; specimens loaded at 28 days curing age showed less creep than those loaded under the same stress at 7 days; springs in creep frames adequately maintained the applied stress.

Structural Research

Shear strength of prestressed concrete I-beams

C. L. Hulsbos, *Proceedings*, Highway Research Board, V. 37, 1958, pp. 106-118

Author's Summary

Reports preliminary results of tests of four prestressed I-beams, three with reinforcement omitted from the shear span. The shear span was the only variable, ranging from 3 to 4 ft. Cracks almost coincided with stress trajectories determined from an elastic analysis; the concrete failed on a plane perpendicular to the direction of the principal tension.

Addition of web reinforcement to the fourth beam did not materially change the shear strength of the beam, but the ratio of ultimate strength to shear strength was greater than for beams without web reinforcement.

A modified maximum tensile stress theory of failure, accounting for some plastic redistribution of stress within the concrete, was compatible with computed nominal critical stresses at failure. The test results indicate that this limiting stress varies between the tensile strength and the modulus of rupture.

Shear cracks usually began in the web between the neutral axis and the flange-web junction in the presence of critical tensile stresses. Shear cracks may also originate at the bottom fibers when the tensile stresses there exceed the modulus of rupture and the tensile stresses in the web are close to the critical value.

Forces created during driving of concrete piles

Sven Sahlin, *Road and Safety Construction* (Stockholm), No. 5, 1956; reprinted by Kungliga Tekniska Hogskolan, Stockholm

Reviewed by Carl H. Gustafson

Driving tests were conducted and the conclusion reached that Hiley's formula must be reduced by 10 percent when no head is used and by 50 percent when the head is used, to agree with the recorded values. (For two piles only.)

The pile was assumed homogenous and therefore peripherial values can be assumed safe.

As a result of the tests, the following conclusions may be reached pertaining to the dynamic forces created during driving.

1. Hooke's law is applicable.
2. Forces may be measured by a combination of Wheatstone bridge and oscillograph.

12-m span vault of narrow corrugated plates (in Polish)

J. Hartwig, *Bulletin* ITB No. 239, Institute of Building Technology, Warsaw, 1957, 20 pp.

Polish Technical Abstracts No. 2 (30), 1958

Reports tests on a reinforced concrete roof of prefabricated narrow corrugated plates of double curvature. The span of the roof was 12 m and the rise 2 m. Dimensions of the corrugated plates were 2.75 x 0.5 m and 3 cm thick.

State of stress and buckling of a circular conoid (in Polish)

A. Lisowski and G. Siefer, *Inzynieria i Budownictwo* (Warsaw), No. 10, 1957, pp. 360-365

Polish Technical Abstracts No. 2 (30), 1958

Authors attempt to compute the stresses and failure loads in a short conoidal shell. The state of stress in the shell is analyzed on the basis of the diaphragm theory. The theoretical computations were checked by model tests which showed that the actual value of internal forces acting in the shell is greater than the computed value using the diaphragm theory.

Torsional properties of prestressed concrete

ROBERT HUMPHREYS, *The Structural Engineer* (London), V. 35, No. 6, June 1957, pp. 213-224
Reviewed by C. P. SIESS

Reports tests on 94 rectangular plain concrete beams prestressed concentrically or eccentrically with unbonded tendons. Variables were size and shape (ratio of sides) of beams and level of prestress. Only one quality concrete was used. All failures were in tension and results were in accord with theory of failure based on maximum principal tension stress. Effect of compressive prestress was diminished as its value approached about three-fourths the ultimate compressive strength. Recommendations given for design. Excellent bibliography and summary of previous tests.

Pile test loads compared with bearing capacity calculated by formula

M. G. SPANGLER and HARRY F. MUMMA, *Proceedings*, Highway Research Board, V. 37, 1958, pp. 119-149

Compares actual bearing capacity of 59 individual piles, as revealed by load test, and the bearing capacity of the same piles calculated by four different dynamic pile formulas. Although considerable computation is required, the Rabe formula was found to be the most reliable of those examined and in the cases studied gave safe and economical results.

Test results of assembled reinforced concrete flat slab structure (in Russian)

K. K. ANTONOV, *Bulletin Stroitelnoi Tekhniki* (Moscow), V. 15, No. 2, Feb. 1958, pp. 10-15
Reviewed by HERBERT E. KESE

Scale model of a floor of a flat slab type construction assembled of prefabricated reinforced concrete parts, and consisting of four interior panels and the columns spaced 6 m on centers both ways was built and tested. Column section was 40 cm square; column strip slab thickness 8 cm; middle strip, 9 cm. The capitals were 2.5 m square. All designed for a uniform live load of 1000 kg per sq m. Conclusions from the test are reported. Furthermore, it is stated that this type of construction is something new and needs more exploration to arrive at better methods of design and to increase its economical usefulness.

General

Preparation of samples for microscopic investigation

ERVIN POULSEN, *Progress Report* M1, Committee on Alkali Reactions in Concrete, Danish National Institute of Building Research and Academy of Technical Sciences, Copenhagen, 1958, 46 pp., 12 D. kr.

The report describes the methods of collection and preparation of samples of concrete and aggregates for microscopic investigation developed and used by the petrographic laboratory of the Committee on Alkali Reactions in Concrete. Particular attention is given to thin section techniques.

Bibliography of engineering seismology

EDWARD P. HOLLIS, Earthquake Engineering Research Institute, San Francisco, 1958, 166 pp., $4.50

Over 2000 entries and cross references to the voluminous literature related to engineering seismology. The bibliography is conveniently divided into miscellaneous sources of data; geology, geodesy, and seismology; seismometry and dynamics of structures and soils; and design and construction in seismic regions. A useful tool for investigative work in this field.

Apartments and dormitories

EDITORS OF *Architectural Record*, F. W. Dodge Corp., New York, 1958, 238 pp., $8.95

An illustrated survey of some outstanding multiple dwellings. The 53 projects chosen were selected from among those published in *Architectural Record* during the past several years. The projects are grouped under four headings: apartments–community scale projects; apartments–large projects; apartments –small projects; and campus dormitories and apartments.

The initial section of the book contains material on economic and sociological problems and trends in housing, and some of the technical aspects of apartment construction such as heating, partition walls, vertical transportation, and cost cutting techniques.

Although the book will give developers, owners, and architects an excellent survey of what has been done, it is somewhat disappointing to find that more space was not given to structural design and construction technology, including materials. The value

as a reference book could have been improved with more articles of the same nature as the two on how "Cost of Multistory Building Can Be Cut" and "Partitions Function as Columns."

Fiftieth anniversary history—American Concrete Pipe Association

HOWARD F. PECKWORTH, American Concrete Pipe Association, Chicago, 1958, 122 pp.

Presents the experiences and personalities involved in the growth and activities of the first 50 years of the American Concrete Pipe Association since its inception in 1907.

Glossary of concrete masonry terms

Concrete, V. 66, No. 8, Aug. 1958, pp. 29-33

The National Concrete Masonry Association has completed a preliminary glossary of terms relating to concrete masonry. The glossary has been divided into four sections: manufacturing, concrete masonry units, design and construction, and references.

Further development of technical criteria for concrete (Weiterentwicklung der betontechnischen Bestimmungen)

K. WALZ, *Der Bauingenieur* (Berlin), V. 33, No. 1, Jan. 1958, pp. 10-14

Reviewed by ARON L. MIRSKY

The 1943 German standards for concrete and reinforced concrete construction, DIN 1045 and 1047, are currently being revised. Paper is a discussion, with examples, of improved methods of design of mixes for both regular and "special" concrete. The importance of competent supervision is emphasized.

Editorial notes from Concrete and Constructional Engineering

H. L. CHILDE, Concrete Publications, Ltd., London, 1958, 96 pp., $1.75

Generally nontechnical in the usual sense, this collection of editorials covering a span of 36 years should be of interest to engineers concerned with their place in society and in the educational standards for future engineers. The main purpose is to encourage engineers and scientists to explore beyond technical problems. Closely allied is the aim to convince opponents that a well-rounded individual is a more useful member of society and a happier man than one who is master of a technical subject only. It is further the author's hope to encourage engineers to say and write exactly what they mean.

Many of the problems discussed pertain to Britain but this does not detract from the interesting discussion applicable anywhere. The thought-provoking, penetrating analyses of the engineer's relations with the world around him are well worth reading.

Minimum property standards for one and two living units

Federal Housing Administration, Nov. 1, 1958, 300 pp., $1.75 (available from Superintendent of Documents, Government Printing Office, Washington 25, D. C.)

Performance standards and over-all requirements on a nation-wide basis subject to local exceptions replace the rigid rules and detailed specifications of the present 23 regional manuals. Tentative effective date is Apr. 1, 1959, but may be postponed if necessary to permit the housing industry to conform. The revised standards are intended to make local approval easier and may encourage revision of antiquated housing codes used by some communities.

Compatibility of aluminum with alkaline building products

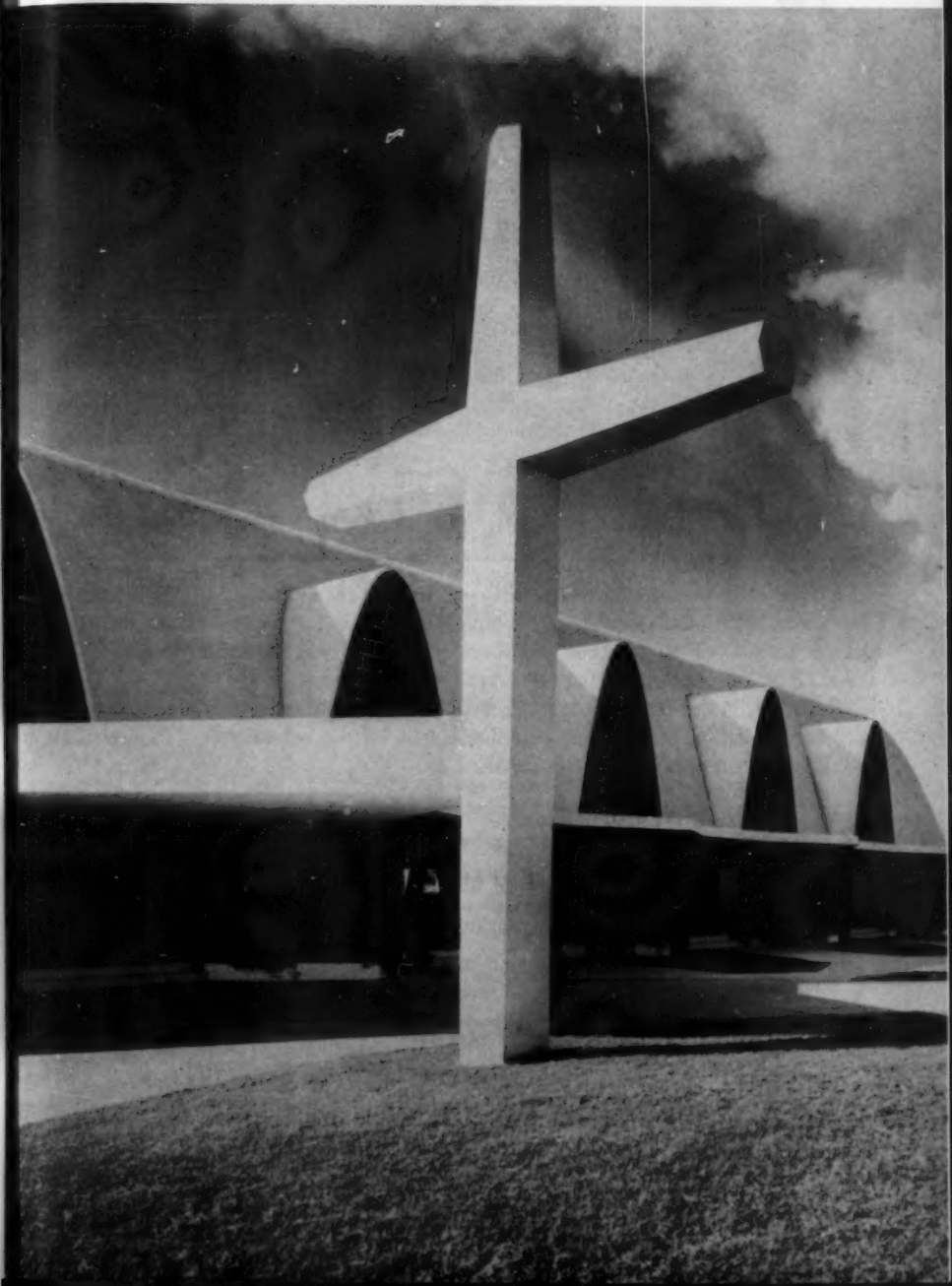
C. J. WALTON, F. L. MCGEARY and E. T. ENGLEHART, 13th Annual Conference, National Association of Corrosion Engineers, St. Louis, Mar. 11-15, 1957; reprinted by Alcoa Research Laboratories, Aluminum Company of America, 17 pp.

Results of tests to determine performance of aluminum alloys in contact with a wide variety of alkaline building materials are summarized and discussed in connection with many service experiences. Several specific investigations on the effects of concrete on aluminum alloys are described in detail. Included are results of evaluations on admixtures, cathode size in galvanic circuits, complete and cyclic immersion in water, and stray currents.

In some installations, the presence of chlorides, dissimilar metals, leakage currents, differential aeration effects, or combinations of these factors may necessitate the use of protective measures. Information included in this paper should be of assistance in resolving these problems in a practical manner.

ACI News Letter

Vol. 30, No. 8 JOURNAL of the AMERICAN CONCRETE INSTITUTE February 1959



American Concrete Institute

This is to Certify that

John Smith

is a

Member

of this institute and fully entitled to the privileges granted by its Charter and Bylaws

_____
President

_____
Secretary-Treasurer

Date of membership: July 1, 1952

Above is shown the membership certificate now available to all interested members. (Student members become eligible for certificates when they advance to one of the higher membership grades.) The actual certificate is 10 x 12 in. on parchment paper suitable for framing.

Return this order form together with your remittance—to avoid the added expense of billing—and your certificate will be mailed to you. Please allow 90 days for preparation of the certificate.

Please accept my order for a membership certificate at the price of $2.00.

☐ Check ☐ M.O. Enclosed

My name is to appear exactly as follows:

_____
(Print or type)

Signature_____

ACI

News Letter Contents

February 1959

On the Cover—Santa Maria Reina Church at Ponce, Puerto Rico, largest Catholic church in the Carribean area, is roofed with thin shell concrete of catenary cross section, supported by two-hinge catenary arches. Synthetic rubber provides a gleaming white roof surface that cuts heat in the interior. More structural details appear on p. 5 of this News Letter

55th Annual ACI Convention..... 3

Concrete Catenaries in the Carribean..... 5

Bonding of Cementitious Materials..... 7

Positions and Projects.....11

Prestressed Concrete Bents.....13

Henry N. Walsh.....14

Memorial Fund.....14

Hyperbolic Paraboloids Roof Garage.....15

Honor Roll.....19

New Members.....19

Tools, Materials, Services..21

Looking Ahead.....25

List of Advertisers.....32

Record Attendance Expected at

55th Annual ACI Convention

All indications point to a record attendance at the 55th Annual ACI Convention scheduled for February 23-26 at the Statler Hilton Hotel, Los Angeles.

An outstanding technical program, special entertainment highlights, and an opportunity to enjoy a midwinter vacation in California are added incentives to attend this annual meeting.

Technical committee "working sessions" and the annual business session will take up the first two days of the convention program, February 23 and 24.

First general session is scheduled for Tuesday afternoon, February 24, and will consider revision of ACI Bylaws, and new and revised standards. The standards to be presented for adoption cover hot weather concreting; proportioning of lightweight aggregate structural concrete; and measuring, mixing, and placing concrete.

Full technical program will begin on Wednesday, February 25, with six sessions scheduled through Thursday noon, to be followed by the final research session Thursday afternoon.

Concurrent sessions Wednesday morning will feature construction and special problems in concrete. Topics to be covered at the construction session include erection of precast concrete; joinery of precast elements; discussion of concrete pavements on cement-treated subgrades in California; qualification plan for ready-mixed concrete plants; and cast-in-place concrete pipe. At the session on special problems in structural concrete, papers will be presented on the properties of shielding concrete, design of special purpose blast

resistant structures; and the influence of grade of steel on blast resistance of reinforced concrete beams. Surface precooling to prevent cracking of mass concrete is also scheduled for discussion at this session.

Design analysis

Concurrent sessions Wednesday afternoon will be on design and analysis, and concreting materials and methods. At the design and analysis session speakers will discuss design of prestressed concrete lift slabs for deflection control; effect of longitudinal forces on a portal frame supporting a highway bridge deck; prestressed concrete shells for grandstands and roofs; and pavements continuously reinforced with deformed bars.

Subjects such as the evaluation of concrete and mortar mixes, shotcrete, tremie concrete controlled with admixtures, and concrete and concrete materials for Glen Canyon Dam will be covered at the materials and methods session.

Design research

Thursday morning sessions will feature design research, and products and precast elements. Subjects to be discussed at the design research session include the effect of bar cutoff on bond and shear strength of reinforced concrete beams; shear strength of two-span continuous reinforced concrete beams; torsional resistance of reinforced concrete; and behavior of a continuous concrete slab prestressed in two directions. At concurrent session devoted to products and precast elements, papers will be presented on precast and prestressed folded plate slabs; plastic forms for architectural concrete; exposed aggregate type of decorative panels; glazed face concrete block; and linings for concrete pipe and structures under sewage conditions.

The technical program will culminate Thursday afternoon with the annual research session, an open meeting of ACI Committee 115. A group of short papers will be presented on research techniques and preliminary results of investigations now in progress.

The annual awards luncheon, a feature of the ACI meeting, will be held on Wednesday, February 25.

Entertainment events

Augmenting the fact-filled technical sessions, an impressive schedule of entertainment events has been arranged by the local entertainment chairman, C. Taylor Test. Ladies have been given prime consideration in the entertainment planning, with two activities planned solely for them, in addition to other events for all convention participants.

Both delegates and wives are invited to make the trip to world-famous Disneyland on Friday, February 27, following the conclusion of the official convention program. All conventioneers are invited to the social hour slated for Wednesday night, February 26, which will have a "Pacific island" setting.

In addition to these planned events, tickets to popular television shows and reservations for famous Los Angeles and Hollywood restaurants and night spots will also be available for convention attendants.

An exhibit will be held in conjunction with the convention, and as an added feature of the convention, the exhibits committee will hold a competition for southern California students with awards for models and other presentations depicting concrete designs and applications. Glen C. Thomas heads the exhibits committee.

Local committee

Sam Hobbs, local general chairman for the 1959 ACI convention, announces that Henry M. Layne will act as chairman of the reception committee for the convention. Other members of the general committee assisting Chairman Hobbs, secretary-treasurer, ACI Southern California Chapter, include: William F. Norton, Ceco Steel Products Corp., treasurer; Ross Adams, Portland Cement Association; Ernest Maag, California Division of Architecture; John McNerney, Portland Cement Association; Lewis K. Osborn, Kistner, Wright, and Wright, architects; O. C. Struthers, Raymond Concrete Pile Co. and Byron P. Weints, Consolidated Rock Products. In addition, the ladies contingent is headed by Mrs. C. Taylor Test as chairman, with Mrs. Ray Cooley assisting her. More than 30 other members and wives round out the various subcommittees.

ROOF COATING of gleaming white synthetic rubber was sprayed on in two layers, using conventional equipment

CONCRETE CATENARIES in the Carribean

THIN CONCRETE SHELLS roof the church of Santa Maria Reina, largest Catholic church in the Carribean area. Main elements of the structure at Ponce, Puerto Rico, are catenary arches of approximately 54 ft span, 20 ft on centers, supporting a cylindrical shell of catenary cross section only 3 in. thick (see New Letter cover photo). The entire structure, 235 ft long, is divided in half by an expansion joint.

The thin shell is pierced by catenary windows which are limited by small catenary shells intersecting the main shell. The structure is supported on a concrete foundation of heavy beams which act as tie rods for the two-hinged arches.

Reinforcement over most of the shell consists of a welded steel mesh, supplemented around the edges to take care of local bending in the shell. Although the required shell thickness is not more than 2 in., it was made 3 in. thick to facilitate the concreting operations. Welded steel mesh was selected for considerations of strength in a two-dimensional resisting structure, and because it could be easily placed on the forms.

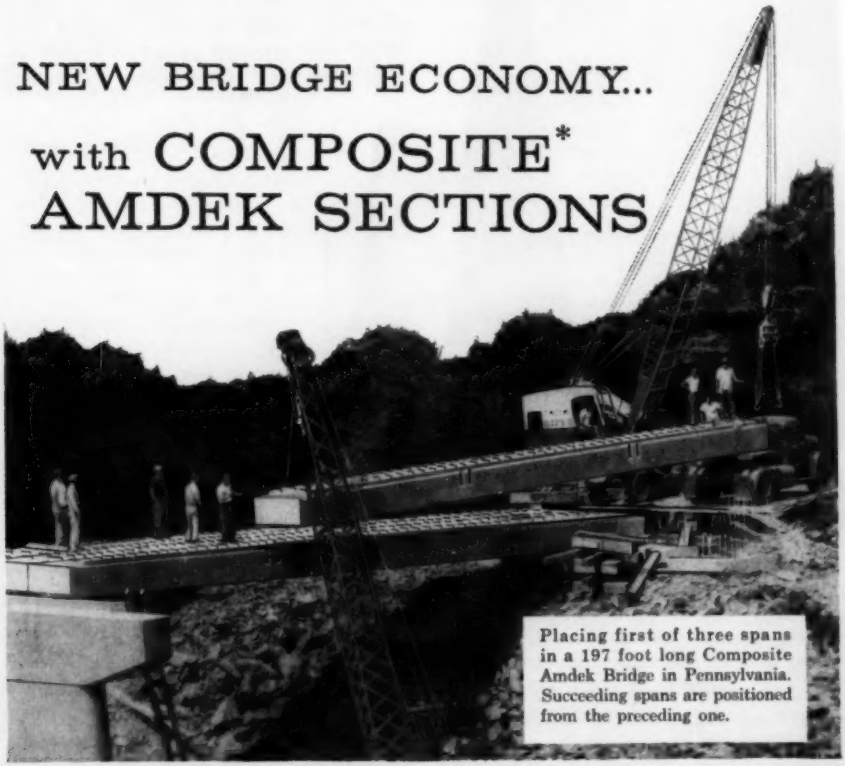
Stress calculations on which the design was based took into account not only live and dead load on the structure, but also wind loads, loading due to differences in temperature between arches and shell, and the important stresses due to shrinking of the concrete.

The 24,000 sq ft of roof area were surfaced with white synthetic rubber, exposing a reflective surface to the torrid sun to keep the interior of the church cooler. A primer coat and top coat of Hypalon synthetic rubber were sprayed on with conventional spray equipment at a rate of 2 gal. per 100 sq ft per coat. This elastic roof coating expands and contracts with temperature variations.

The church was completed in 1957 at a total cost of $296,000. Architects were O'Kelly and Mendez, San Juan, Puerto Rico. Designer was Carl Brunner, Jr., Princeton, N. J., and Mario G. Salvadori, New York, N. Y., served as structural consultant. The general contractor was Santoni and Bivoni, San Juan.

NEW BRIDGE ECONOMY...

with COMPOSITE* AMDEK SECTIONS



Placing first of three spans in a 197 foot long Composite Amdek Bridge in Pennsylvania. Succeeding spans are positioned from the preceding one.

Another example of American-Marietta PROGRESS in CONCRETE

*After the new four-foot wide Composite Amdek Sections are positioned, a four-inch concrete deck is cast over the raised stirrups. The box sections and surfacing then become an integral working unit.

Composite Amdek Sections with concrete surfacing require less concrete, less handling and no form work—which results in considerable savings. Independent dynamic tests have proven their tremendous fatigue strength.

For information on this and on standard three-foot wide Amdek Beams without raised stirrups for use under asphalt surfacing, contact American-Marietta Company.

A·M

AMERICAN-MARIETTA COMPANY

CONCRETE PRODUCTS DIVISION

GENERAL OFFICES:
AMERICAN-MARIETTA BUILDING
101 EAST ONTARIO STREET, CHICAGO 11, ILLINOIS, PHONE: WHITEHALL 4-5600

Bonding of Cementitious Materials

By DANIEL J. GOEKE

BONDING MATERIALS in many cases stronger than the substances being bonded have taken much of the time lag out of concrete repair. Formerly it was necessary to chip, drill, roughen, acid-wash, or scarify old concrete before applying the slurry coat of cement to bond the new concrete topping. Often this was not 100 percent effective. Today's bonding materials simplify the bonding of new toppings to old, and with them plaster may be applied directly to concrete or any structurally sound surface.

Basically the following type agents are available for bonding cementitious materials: synthetic latex emulsions; epoxy resins; and aqueous resins of the vinyl type. Films of these bonding materials may range in temperature from − 35 F to + 300 F without a failure in the bond. Tensile strength varies from 50 to 1200 psi depending on the bonding materials and the materials being joined together. Minimum shear strength is about 175 psi.

Why are bonding materials so strong? How do they work? First, a mechanical bond is achieved by penetration of the bonding material into the pores of the old surfaces, forming a mechanical interlock. Secondly, as the moisture evaporates from the bonding material, adhesion takes place. Third, a chemical reaction occurs as the new material is applied. The bonding agent penetrates voids and forms a bond within the crystalline structure of the new concrete, plaster, or mortar.

Mr. Goeke is vice-president, Larsen Products Sales Corp., Bethesda, Md. His remarks here are condensed from an address presented at the Building Research Institute's Conference on Adhesives and Sealants in Building, Dec. 4 and 5, 1957, in Washington, D. C. Full text of the paper was published by BRI in its proceedings of the conference.

Synthetic latex emulsions

The synthetic latex emulsions are used as an admixture in cementitious materials, giving these normally brittle substances resilience, elasticity, durability, and good adhesion. New concrete can be bonded to old either by adding the latex bonding agent to the new concrete or by using a thin mortar mixed with latex to form a paste which is spread on the old surface before the new topping is applied to the base.

Epoxy resins

Epoxy adhesives consist of liquid polymer, liquid epoxy resin, amine catalyst, and inert filler. By varying the type and amount of each ingredient, innumerable variations in adhesive properties may be obtained. Epoxy adhesives permit bonding of old concrete to old concrete as well as new concrete to old. When using these materials, care must be taken to apply topping before the adhesives have dried out. Such materials differ in nature from a straight film of aqueous resinous emulsions of the vinyl type. The latter dry to a film state before topping material is applied.

Aqueous resins of the vinyl type

The aqueous resinous emulsions of the vinyl type will bond new plaster base or finish coats to concrete, or to any structurally sound surface. The same applies to bonding concrete. These liquid plastics have a viscosity about equal to paint for the sole purpose of application. The dried film is stable when the water has evaporated, and remains flexible, free from any tendency to harden or crack. This flexibility assures both per-

mament adhesion and ageless bond. The vinyl type of bond is verminproof, nontoxic, nondeteriorating, incapable of supporting flame, and highly resistant to most acids and alkalies.

Good construction techniques essential

Modern bonding materials are by no means a cure-all; they are effective *only when correctly applied to structurally sound bases.* It is now possible to bond cementitious materials to any structurally sound surfaces, such as glass, marble, tile, steel, wood, lead, concrete, and oil-painted surfaces, but a few simple rules must be followed:

1. The surface must be structurally sound.

2. All surfaces should be free of rust, grease, oil, or wax.

3. Do not apply over water soluble paints, frozen concrete, or dead plaster.

4. Smooth, glossy, porous or semiporous surfaces that are clean and dry need no special surface preparation.

5. Select a product whose manufacturer offers the best in research, engineering materials, production techniques, and human abilities.

6. Follow the manufacturer's specifications.

7. Use the material for the purpose it was designed.

8. Adhere to good mechanical practices.

New construction—plaster or mortar on concrete

In new reinforced concrete slab construction, bonding agents have eliminated the costly operation of chipping, grinding, and polishing concrete ceilings. Today plaster or acoustical plaster may be bonded directly to exposed concrete surfaces. After the forms have been removed, a vinyl bonding material is sprayed on without any prior preparation, then allowed to dry to the touch before plastering. The finished coat of plaster is applied directly to the coated concrete, covering fins and filling hollows by doubling back. Sometimes months elapse before the plaster is applied to the bonding agent. This in no way affects the bond. As a matter of fact, it is common practice on large apartment houses, hotels, and office buildings to follow this procedure.

In the Havana Hilton Hotel recently built in Cuba, bonding agents were used to bond plaster to all the ceilings and other exposed concrete surfaces. The reinforced concrete elevator shaft connecting the hotel's two main wings received, on the exterior, a bed of mortar bonded to the shaft to serve as a base for mosaic tile. The tile backs were coated with a bonding agent, and bonding agent was used in the grout to prevent it from drying out, cracking, and falling out.

Restoration and repair work

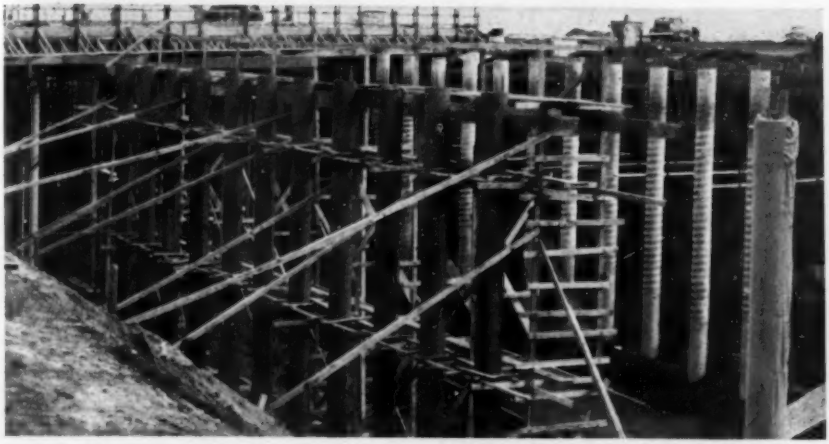
Bonding agents were used to renovate the 28-year-old Lincoln Hotel in New York, now named the Hotel Manhattan. Webb and Knapp Construction Co. faced the problem of making new smooth walls out of old, oil-painted, rough textured walls. To remove all the plaster from 33 stories was out of the question. Their solution was to remove all loose paint and dead plaster, spray all walls and ceilings with a vinyl bonding agent, and put a $\frac{1}{16}$-in. coat of white lime putty plaster over the old walls. The 1400 rooms on the 33 floors were done in this manner. Here bonding agents eliminated the tearing out of old plaster, relathing, and putting an expensive three-coat plaster job on the walls and ceilings.

Bonding agents have been used successfully in varied types of renovations: bonding plaster to old tile, to old glass block, to lead x-ray shields; bonding a mortar bed to an oil painted surface for ceramic tile, and to many other structurally sound surfaces.

Recently the Eaton Manufacturing Co. in Cleveland had the problem of installing two 75-ton milling and drilling machines on piers projecting above a 36-in. base slab. To cast these 80 piers and the slab in one operation was an expensive proposition. It was decided to place the base slab, cure it, and then place the forms for the piers. A bonding agent was brushed on the base slab at spots where the 80 piers were to be placed. With the simplest forms, these 8-in. piers were later cast with assurance of a permanent bond to the base slab. No reinforcing rods were used to anchor the piers. The two 75-ton machines have been operating successfully on these piers about 2 years.

FIBRE FORMS

Save time, money and labor!



Overpass on Bayshore Freeway, Redwood City, Cal. Piombo-M & K, contractors. California Division of Highways, designers.

Use low-cost, easy-to-handle

Sonoco *Sonotube*® FIBRE FORMS

for round columns of concrete

Contractors save time, labor and money when Sonotube Fibre Forms are used to form any round concrete columns . . . for overpasses, bridges or buildings.

Low-cost, Sonotube Fibre Forms are approved by engineers and architects and are widely used by contractors everywhere. Because the fibre forms are lightweight and easily handled, placing is simple and only minimum bracing is required.

See us at Booth 30 A.C.I. Convention

For the fastest and most economical method of forming round columns of concrete, use Sonotube Fibre Forms.

Available in three types, Seamless (premium form for finished columns), "A" Coated (standard form for exposed columns) and wax coated. Sizes from 2" to 48" I.D. Can be sawed to size on the job. Order in required lengths or in standard 18' lengths.

See our catalog in Sweets.

For complete information and prices, write

- HARTSVILLE, S. C.
- LA PUENTE, CALIF.
- MONTCLAIR, N. J.
- AKRON, INDIANA
- LONGVIEW, TEXAS
- ATLANTA, GA.
- BRANTFORD, ONT.
- MEXICO, D.F.

SONOCO

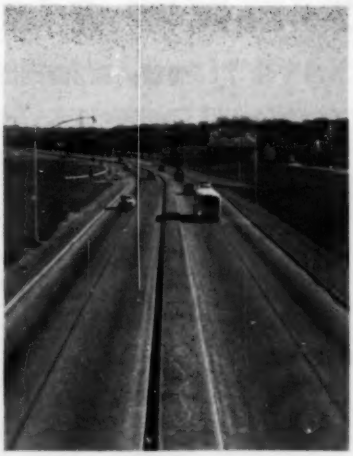
Construction Products

SONOCO PRODUCTS COMPANY

3610 -A

Serving throughout the country with improved efficiency and lower maintenance cost . . .

PAVEMENT CONTINUOUSLY REINFORCED WITH RAIL STEEL BARS



Continuously rail-steel-reinforced pavement is providing improved road service and efficiency everywhere it has been laid. In every type of climate and local environment, and with up to maximum traffic loads, pavement continuously reinforced with high-strength rail steel offers smoother riding roads, with longer life and often no maintenance. There's no faulting or pumping. And since there are no troublesome, crack-breeding joints, no maintenance or repair is needed. Here are just a few of the many examples of this kind of performance:

Indiana (US 40), 21 Years—*On pumping soil with no granular base. Heavy traffic, 8,000 vehicles a day. No slab maintenance or repair.*

Illinois (US 40), 12 Years—*On pumping soil with no granular base. Heavy traffic, 10,000 vehicles a day. No slab maintenance or repair.*

New Jersey (US 130), 12 Years—*On granular sub-base over pumping soil. Excessive truck traffic. No crack or joint maintenance.*

California (US 40), 10 Years—*Prepared granular base on pumping soil. Heavy traffic, high percentage trucks. No slab maintenance.*

Texas (Fort Worth Freeway), 8 Years—*Granular sub-base on pumping soil. Excessive traffic, 40,000 vehicles a day. No slab maintenance.*

In addition to this smooth, long-life, repair-free record, you'll find continuous pavement reinforced with rail steel bars has a low initial cost . . . cost per square yard is similar to that of standard reinforced concrete pavement with joints.

Assure this improved efficiency and lower cost for your next paving job. Investigate continuous pavement reinforced with high-strength rail steel bars. For more details, write or phone for our 16 mm color film, "Advancement in Concrete Pavement."

RAIL STEEL BAR ASSOCIATION

38 SOUTH DEARBORN STREET • CHICAGO 3, ILLINOIS

Positions and Projects

ACI Technical committee appointments

Listed below are committee members who have recently accepted appointments to ACI technical committees. Included are *new* appointments only.

Committee 115, Research

Manuel Rocha
Laboratorio Nacional de Engenharia Civil
Lisbon, Portugal

Committee 623, Cellular Concretes

C. W. Foster
Reflectal Corp.
Chicago, Ill.

President McHenry installs Oklahoma Chapter officers

ACI President Douglas McHenry formally installed officers of the recently organized ACI Oklahoma Chapter at a dinner held January 14 at the Student Union Building, Oklahoma State University, Stillwater. The dinner was part of the 9th annual Southwest Concrete Conference held at the University on January 14 and 15.

Chapter officers include Daniel Hapke, Portland Cement Association, Oklahoma City, president; Richard Jackson, Black and West, Architects, Tulsa, vice-president; and Robert P. Witt, Oklahoma State University, secretary-treasurer. Three directors installed were Calvin Garrett, Scott & Garrett & Associates, Oklahoma City; Stanely Gerlach, McMichael Concrete Co., Tulsa; and Harold Wenzel, Dolese Co., Oklahoma City.

Delmonte addresses Southern California Chapter members

Julian Delmonte, manager of the Building Trades Division, Furane Plastics, Inc., Los Angeles, was guest speaker at the January 20 meeting of the Southern California Chapter of the American Concrete Institute held at the Rodger Young Auditorium. Chapter President Ernest Maag, California Department of Public Works, Division of Architecture, Los Angeles, presided at the meeting.

Mr. Delmonte spoke on "Current Uses of Epoxies for Grouting and Bonding of Concrete," giving a brief history of the development of epoxy resins, their source, and the current merchandising and distribution systems. He discussed pro and cons of base resins, compounding formulations "in the field", and using the services of an epoxy formulator.

Southwest Concrete Conference convenes at Oklahoma State

The 9th annual Southwest Concrete Conference was conducted January 14-15 at Oklahoma State University, Stillwater, by the School of Civil Engineering and the Division of Engineering and Industrial Extension, in cooperation with the Oklahoma Ready-Mix Concrete Association, American Concrete Institute, Portland Cement Association, and the concrete industry of the Southwest.

The conference was arranged by Prof. R. P. Witt of the School of Civil Engineering and Prof. L. F. Sheerar of the Division of Engineering and Industrial Extension.

ACI President Douglas McHenry, director of development, Portland Cement Association, Chicago, was among the speakers participating in the program. President McHenry spoke on current research and new developments in concrete.

Other topics discussed were: problems of the small ready-mixed concrete operator; materials problems; mixing, placing, and structural properties of lightweight concrete; effect of admixtures on concrete; ceramic-faced masonry; aggregate production; and prestressed bridges.

Break ground for new Master Builders headquarters

Master Builders Co. recently broke ground for a new $3,500,000 international headquarters building in Cleveland Heights, Ohio.

The modern, three-story office building is expected to be ready for occupancy in time for Master Builders' 50th anniversary in December 1959.

Yamasaki announces firm name change

Minoru Yamasaki has announced that due to the retirement of Joseph W. Leinweber, the name of the firm of Yamasaki, Leinweber, and Associates, Birmingham, Mich., will be changed to Minoru Yamasaki and Associates.

The principals of the new firm are Mr. Yamasaki, Cass Wadowski, William Jarratt, Frank Straub, and Gunnar Birkerts. Associates of the firm are Harold Tsuchiya, Henry Guthard, Robert Morris, and Richard Albyn.

Walter P. Graydon, formerly associated with the firm of Arthur Froelich, Los Angeles, has joined Yamasaki and Associates as chief draftsman and head of the construction department.

Jessup retires as editor of Civil Engineering

Walter E. Jessup has retired as editor of *Civil Engineering* after 28 years of service with ASCE and the publication with the exception of 3 years on leave for wartime service as an officer in the Corps of Engineers. He was succeeded by Hal W. Hunt, who has been executive editor.

Mr. Jessup was editor of *Civil Engineering* from 1930 to 1935. He then transferred to the position of field secretary of ASCE and later was Washington representative and acting assistant secretary of the Society. He became editor of *Civil Engineering* for the second time in 1948.

Mr. Jessup is planning to live in San Marino, Calif., and resume the practice of civil engineering. He has been an ACI member since 1955.

Eleventh California Street and Highway Conference

The Institute of Transportation and Traffic Engineering and the University Extension, University of California, Berkeley, conducted the eleventh California Street and Highway Conference on January 28-30.

The 3-day conference was devoted to a thorough exploration of new developments in street, road, and highway affairs. Specialists in several fields pertinent to administration, construction, maintenance, and safety addressed group sessions. C. E. Waite, deputy state highway engineer, Sacramento, acted as general chairman of the conference.

Highway Research Board holds 38th annual meeting

The 38th annual meeting of the Highway Research Board was held January 5-9 in Washington, D. C.

In addition to the Board's committee meetings, 41 separate technical sessions were conducted at which approximately 177 research papers and technical reports were presented and discussed.

Various design sessions were devoted to the subject of bridges, flexible pavements, rigid pavements, and skid prevention research. Materials and construction sessions covered construction practices, general materials, concrete and aggregates, bituminous materials, basic research in cement and concrete, concrete durability, and dynamic tests.

Other sessions covered maintenance, traffic, soils, and urban research.

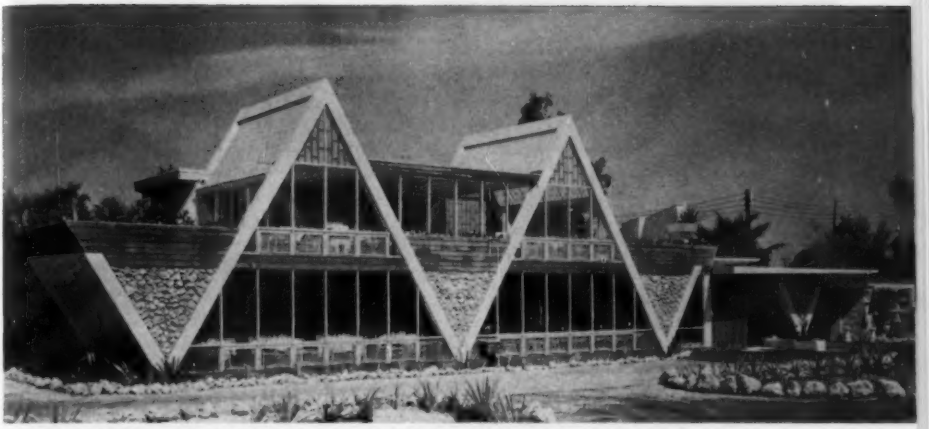
Two testing engineering firms form working agreement

A working agreement between two of California's principal testing engineering and inspection firms went into effect January 1 to provide a greater diversification of services and increased specialization in these technical fields on the West Coast.

Involved are Testing Engineers, Inc., San Diego, and Woodward-Clyde-Sherard and Associates, Oakland. They will specialize in general testing and inspection work, including metallurgical, chemical, and physical testing, as well as concrete, cement, steel, welding, and other inspection.

M. R. Neumann, former vice-president of W-C-S and Associates is northern California director of Testing Engineers with headquarters in Oakland, while E. L. McDonald, formerly of Smith Emery Co., manages the southern California division in San Diego where a new $100,000 administration building and laboratory is being constructed.

Philip Helsley and Mitchell P. Christensen continue as president and vice-president of Testing Engineers, Inc.



a series of economical triangles . . .

A BOLD MOTIF OF CONSECUTIVE TRIANGLES executed in prestressed concrete served as the design nucleus for this Hallandale, Fla., restaurant. Prestressed concrete bents 29 ft high were leaned together, then tied with a second floor running through the center. Not only did the triangles thus become a rigid unit, but the second floor was brought out beyond the frame to form outdoor dining patios on either side.

The 5500 sq ft building rests at six points on 3 ft x 6 ft x 15 in. concrete pads. A cast steel plate on the bottom of each bent was fastened to bolts embedded in the pads. Metal plates installed in the prestressed bents at the second floor level were welded to the end plates of prestressed concrete beams spanning across the bent. Over these were laid, lengthwise from one end of the building to the other, prestressed double-T slabs, 4 ft wide. Simplicity of design helped cut bolting and welding time to a minimum.

A 3-in. topping of smoothly troweled concrete sprayed with plastic base paint was specified for the second floor over the double-T's. No columns obstruct the interior of the 200-seat restaurant, and the absence of bearing walls gave the architect wide latitude in selection of materials for enclosure. Wood, rough coral rock and glass were teamed with 1 9/16 in. thick panels of aluminum grill sandwiched with glass fiber. These translucent panels cut heat and glare of the Florida sun, emit a soft glow at night.

John Edwin May, Hallandale, was architect for the unusual structure. R. H. Wright, Fort Lauderdale, manufactured and erected the prestressed concrete bents and double-T's. The name of the restaurant, aptly, is Out of This World.

Henry N. Walsh

Henry N. Walsh, who last year retired as Dean of the Faculty of Engineering at University College, Cork, Ireland, recently died in Cork.

Professor Walsh graduated from University College, Cork, in 1914. He was awarded a Belt Research Fellowship in the Imperial College, London, in 1915. His research work in London gained him his ME and Diploma of the Imperial College in 1917. He returned to Cork as assistant in the engineering department in the same year and was appointed to the Chair of Civil Engineering in 1921.

Despite his heavy work schedule at the University, Professor Walsh found time to devote himself to research in concrete, a field which earned him an international reputation. In 1939 he published the results of his work in a book entitled "How to Make Good Concrete" which has since become a standard text.

His activities were not confined to the academic field alone. He was president of the Institute of Civil Engineering of Ireland from 1940 to 1942. Professor Walsh joined ACI in 1929.

Memorial Fund

This month contributions to the fund have been received in memory of

Newlin D. Morgan, Sr.
Wilbur M. Wilson

Contributions, comparable to what might otherwise have gone for flowers, can be made in the name of the deceased and an acknowledgment will be sent by the Institute to the member's family.

Second World Conference on Earthquake Engineering

At the world conference on Earthquake Engineering held at Berkeley, Calif., in June 1956, it was deemed appropriate to hold a second similar conference in Tokyo. Accordingly, the Science Council of Japan, which is a governmental organization representing all Japanese scientists for the promotion and development of science and industry, is organizing the Second World Conference on Earthquake Engineering to be held July 11-18, 1960, at Tokyo and Kyoto, Japan.

The Japan Society of Civil Engineers, the Architectural Institute of Japan, and the Seismological Society of Japan will cooperate with the Science Council in the organization and operation of the conference.

The conference will attempt to obtain an exchange of knowledge and experience for the purpose of minimizing earthquake hazards information on recent research in the field, reports on strong motion earthquakes and resulting damage, and new developments in aseismic design and construction practices in various countries.

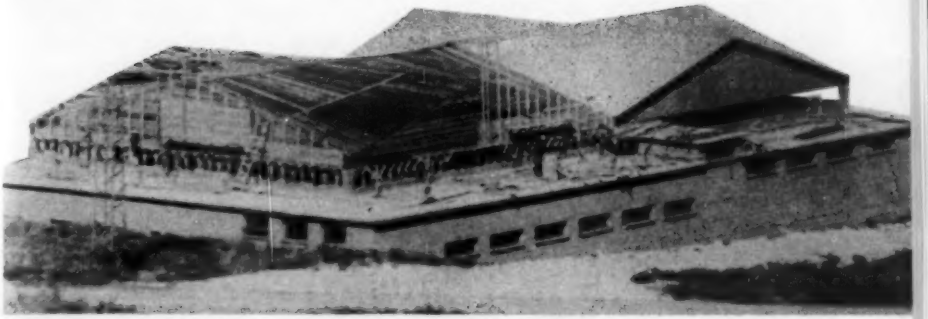
The tentative program includes earthquake ground motion characteristics, response of structures to earthquakes, related soil and foundation problems, earthquake damage and aseismic regulations, and aseismic design and construction. Closing date for submitting papers is Jan. 15, 1960. All papers are to be in English.

English and Japanese will be the official languages at the conference; Japanese will be translated into English. The proceedings will be published after the conference.

Arkansas Cement dedicates new multimillion-dollar plant

Dedication ceremonies of the new multimillion dollar Arkansas Cement Corp. plant at Foreman, Ark., were held January 21.

The new plant with a rated capacity of 1,400,000 bbl annually, will produce all the main types of portland cement as well as masonry cement. Located in southwest Arkansas, the Foreman plant will service customers in the middle south and southwest.



Hyperbolic paraboloids roof garage in Israel

Considerations of economy governed choice of a roof composed of two reinforced concrete domes, each with four warped hyperbolic paraboloidical surfaces, according to Institute member Albert D. Palan who provided the accompanying photograph. The structure, a modern bus terminal at Tiberias, Israel, houses both utilities and storage area and a shop area with working pits. The latter required a maximum of clear, column free area.

Two identical domes are 17.5 x 15 m in plan, with a height of 2.1 m. The interior edges are stiffened by ribs of constant section projecting above the shell so that the inside view of the roof forms an uninterrupted surface. Exterior edges rest on triangularly shaped diaphragms 15 cm thick, supported on four columns. Aside from these corner columns there is a single center column between the two domes.

Warped surfaces of the shells are 6 cm thick, increasing to 10 cm near the edges. Reinforcement of 6-mm twisted bars at 15 cm intervals was placed in two layers in diagonal directions. Forms were built of ¾-in. boards laid in straight lines corresponding to lines generating the warped roof surface.

The structure was designed by Z. Weltsch and Partners, Haifa, Israel. Contractor was Solel Boneh, Ltd., Tiberias Branch.

Lone Star elects two new directors

H. A. Sawyer, president of Lone Star Cement Corp., recently announced the election of Walter F. Law and R. J. Mahon as directors of the company.

Mr. Law has been executive vice-president since February 1957 and Mr. Mahon vice-president for sales since June 1952.

Carolina Solite adds new kiln at Aquadale plant

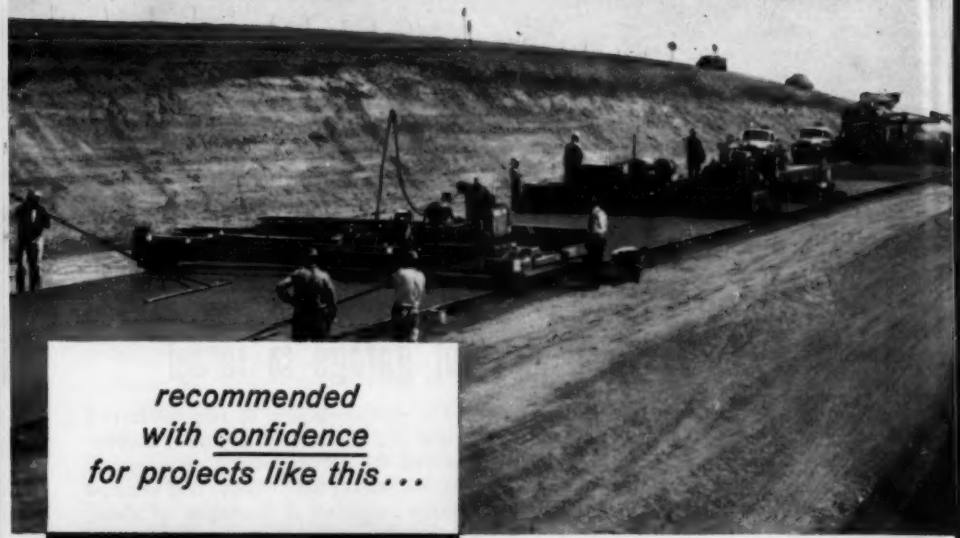
Carolina Solite Corp., a subsidiary of Southern Lightweight Aggregate Corp., has announced the construction of an additional kiln at their Aquadale, N. C., plant. The addition of the 135 ft rotary kiln increases production to equal that of Solite's plant at Bremo Bluff, Va.

National Gypsum to acquire Huron Portland Cement

President Paul H. Townsend of Huron Portland Cement Co., Detroit, has announced that negotiations are being conducted under which Huron would be acquired by National Gypsum Co. He emphasized that no changes in Huron Cement's management, personnel, or method of distribution are contemplated. Mr. Townsend would continue as president.

FIRST NEW HIGHWAY-ACT PAVEMENT . . . BUILT IN 1957

POZZOLITH* improved concrete



recommended with confidence for projects like this . . .

. . . because of performance on projects like this . . .

Above: Section of U. S. Route 40, west of Topeka. Kansas State Highway Commission. Contractor: Koss Construction Co.

Below: Route 5, approximately 5 miles east of Erie. Pennsylvania State Highway Department. Contractor: Geo. S. Mellert-Weidner Company.

BUILT IN 1942 . . .

. . . concrete is in exceptionally good condition today. Another project where superior durability was obtained economically with POZZOLITH-improved concrete.

*POZZOLITH . . . registered trademark of The Master Builders Company for its water-reducing, air-entraining admixture for concrete.

THE **MASTER BUILDERS** COMPANY

DIVISION OF AMERICAN-MARIETTA CO.

General Offices: Cleveland 3, Ohio • Toronto 9, Ontario • *Export:* New York 17, N. Y.

Branch Offices in All Principal Cities • *Cable:* Mastmethod, N. Y.

McCarthy elected chairman of Indiana registration group

James A. McCarthy, civil engineering professor at the University of Notre Dame, has been elected chairman of the Indiana State Board of Registration for professional engineers and land surveyors. Professor McCarthy, an ACI member since 1940, is currently a member of ACI Committee 115, Research.

AGC conducts 40th annual convention

The Associated General Contractors of America held their 40th annual convention in Miami, January 19-22, with a record-breaking attendance of over 2000 persons.

Various sessions were devoted to building construction, highway construction, and heavy railroad construction. The program included a building construction workshop as well as a municipal contractors forum.

International visitors inspect ACI headquarters

L. D. Kyles, Stanley A. Wood, and C. H. Buehner, all of the architectural firm of Kyles and Kyles, Hamilton, Ont., Canada, recently inspected the Institute headquarters building.

Teunis Teunissen of N. V. Schokbeton, Kampen, Holland, also visited the new building last month.

Spinden retires

Emil Spinden, vice-president and chief engineer of Sika Chemical Corp., Passaic, N. J., retired recently but will continue to serve the company as a vice-president and consultant.

Mr. Spinden has been associated with Sika since 1932, first as a sales engineer and later as chief engineer. Considered an authority on repairs, he has directed the repair of a number of important projects, among which were: the Liberty Tubes in Pittsburgh, 1938; the Pennsylvania Railroad transformer vaults under the Hudson and East Rivers in New York City in 1932; the United Electrical Railway Tunnel in Providence, 1945; the Virginia Ave. Tunnel in Washington, D. C.; and portions of the New York City subways.

LABYRINTH WATERSTOPS

A SOUND INVESTMENT FOR CONCRETE CONSTRUCTION!

LABYRINTH AVAILABLE IN 2, 3 or 4 rib.

ON YOUR CONSTRUCTION:

1. Consider the investment in design, materials and labor (to mention a few).

2. Then consider how important safe, secure *watertight* concrete joints are.

3. Thorough watertightness *can* be secured by installing Labyrinth Waterstops – a dividend that makes the low initial cost of the product insignificant when compared to your total investment–and one that insures watertight concrete joints for years!

- Corrugated ribs grip concrete, insure an everlasting bond between joints.
- Finest polyvinyl plastic resists chemical action, aging, severe weather.
- Takes just seconds to nail to form . . . easy to cut and splice on location (prefabricated fittings available).
- There's a Water Seal product for every type of concrete work!

If your aim is to stop water seepage, *stop it effectively with Water Seals' Waterstops!*

"See Us in SWEET'S"

New Literature and Free Samples Sent on Request–Use Coupon Below

WATER SEALS, *inc.*

9 South Clinton Street, Chicago 6, Illinois

Made in Canada for J. E. Goodman Sales, Ltd. Toronto, Ontario

WATER SEALS, INC. DEPT. 5
9 S. Clinton Street
Chicago 6, Illinois
Please send free sample and descriptive literature.

Name_____

Company_____

Address_____

City_____ Zone_____ State_____

add extra years of life to concrete with

CLINTON WELDED WIRE FABRIC

Experienced contractors know that fabric-reinforced concrete lasts longer. And over the years it looks better and requires much less maintenance than unreinforced concrete. Fabric-reinforcement gives these advantages because it adds the tensile strength of steel to concrete . . . resists the heaving and cracking caused by temperature extremes and moisture content . . . minimizes cracking during setting . . . and distributes stress evenly in all directions.

Even if a crack does develop, the fabric holds it tightly together, preserves the smooth surface, and retards further lengthening of the crack. No other type of reinforcement is so easy to install, yet gives so much extra strength for so little cost.

Clinton Welded Wire Fabric is a top-quality product that is readily available in both East and West, in a wide variety of gages, lengths and widths. On your next job, add the tensile strength of steel with Clinton Welded Wire Fabric, and rest assured that you've built a concrete surface that will last longer with minimum maintenance.

WHEN THEY ASK...

"is it Reinforced"

SAY YES...WITH

CLINTON
WELDED WIRE FABRIC
THE COLORADO FUEL AND IRON CORPORATION

CF&I

THE COLORADO FUEL AND IRON CORPORATION—Albuquerque • Amarillo • Billings • Boise • Butte • Denver • El Paso • Ft. Worth Houston • Kansas City • Lincoln • Los Angeles • Oakland • Oklahoma City • Phoenix • Portland • Pueblo • Salt Lake City San Francisco • San Leandro • Seattle • Spokane • Wichita • **WICKWIRE SPENCER STEEL DIVISION**—Atlanta • Boston • Buffalo Chicago • Detroit • New Orleans • New York • Philadelphia • **CF&I OFFICES IN CANADA:** Montreal • Toronto
CANADIAN REPRESENTATIVES AT: Calgary • Edmonton • Vancouver • Winnipeg

6085

Honor Roll

January 1-31, 1959

David A. Sauer proposed 5 new members this month putting him in first place at the beginning of the new Honor Roll year.

New ACI members stem from various sources, however the greatest number are prompted to membership by persons already on the membership rolls of the Institute. They realize the applicant will receive the last word pertinent to the manufacture and use of concrete through the medium of the ACI Journal which is published monthly.

David A. Sauer	5
Joachim F. Leppmann	2
Rafael Enrique Pacheco	2
C. K. Wang	2

New Members

The Board of Direction approved 52 Individual applications, 4 Corporation, 16 Junior, and 16 Student applications making a total of 88 new members. Considering losses due to resignations, retirements, and nonpayment of dues the total membership on Jan. 1, 1959, was 9723.

Individual

ALEXANDER, JOHN, Upper Montclair, N. J. (Cons. Engr.)

ALI, MD. EMDAD, Kushtia, East Pakistan (Exec. Engr., Ganges-Kobadak Project)

ANTELL, HARRY B., Haddon Heights, N. J. (Struct. Engr., United Engrs. & Constrs.)

BAKER, K. E., Tonawanda, N. Y. (Tech. Service Repres., Silicones Div., Union Carbide Corp.)

BERWANGER, CARL, Winnipeg, Canada (Asst. Prof., Dept. of Civil Engrg., Univ. of Man.)

BONATO, EMIL, Niagara Falls, Canada (Tech. Supv., Betoma North-America)

BORRELLO, FILIPPO, Newark, N. J. (Struct. Designer, Edwards & Kelcey)

BRIGHTBILL, LINWOOD J., Urbana, Ill. (Assoc. Prof. of Arch., Univ. of Ill., & Cons. Engr.)

BUKACZEWSKYJ, JAROSLAW, Bronx, N. Y. (Struct. Engr., Severud, Elstad & Krueger Assoc.)

BUSTILLOS, RAUL J., Caracas, Venezuela (Struct. Engr., Dept. of Pub. Wks.)

CHAMBERS, WILLIAM L., Morgantown, W. Va. (Instructor in Civil Engrg., W. Va. Univ.)

CLAPP, EDGAR T., Harrisburg, Pa. (Cons. Engr.)

COVINGTON, JAMES F., Mercer Island, Wash. (Sales Engr., Chas. R. Watts Co.)

COWAN, R. S., Perkasie, Pa. (Struct. Engr.)

DAVIS, F. N., Salt Lake City, Utah (Chf. Designer, Utah Power & Light Co.)

DECKER, EDWIN A., Charlotte, N. C. (Sales Engr., Master Bldrs. Co.)

EDWARDS, CHARLES H., JR., Ruston, La. (Assoc. Prof. of Civil Engrg., La. Polytechnic Institute)

EPSTEIN, SIDNEY, Chicago, Ill. (Vice-Pres., A. Epstein & Sons, Inc.)

FERGUSON, RICHARD, Omaha, Neb. (Sr. Struct. Engr., Henningson, Durham & Richardson, Inc.)

FLAGLER, EUGENE A., Oroville, Calif. (Asst. C. E., Dept. Water Resources, State of Calif.)

GENTNER, WARREN A., Hartford, Conn. (Deputy Mgr. & Chf. Engr., Water Bur. of the Metropolitan Dist.)

PROFESSIONAL CARD

JACKSON & MORELAND, Inc.
JACKSON & MORELAND INTERNATIONAL, Inc.
Engineers and Consultants
Electrical—Mechanical—Structural
Design and Supervision of Construction for
Utility, Industrial and Atomic Projects
Surveys—Appraisals—Reports
Machine Design—Technical Publications
Boston **New York**

GOODMAN, CHARLES H., Chicago, Ill. (Mgr., Prestressed Concrete, Lightweight Aggregate & Research Div., Material Service Corp.)

GORDON, LESLIE, Edinburgh, Scotland (Partner, Kinnear & Gordon)

GRAMBYE, C. V., Gentofte, Denmark (Struct. Engr., Messrs. Lemvigh-Muller & Munck A/S)

GREAVES, DR. MELVIN J., Cleveland, Ohio (Asst. Chf. Engr., Arthur G. McKee & Co.)

GUILLERMETY, PROF. F., Detroit, Mich. (Prof., Detroit Inst. of Tech.)

HUNTER, RAYMOND T., Clayton, Mo. (Concrete & Steel Structures Co.)

IACOBUCCI, JOSEPH A., Astoria, N. Y. (Struct. Engr., M. W. Kellogg)

INTLEKOFER, CHARLES F., Seattle, Wash. (Asst. Bridge Engr., Great Northern Railway Co.)

JACKSON, R. W., Tulsa, Okla. (Struct. Engr. & Arch., Black & West)

LAZAR, RONALD, Winnipeg, Canada (Asst. Prof. of Civil Engrg., Univ. of Man.)

LOWELL, RICHARD A., Oakland, Calif. (Engr. (Sales) Master Bldrs. Co.)

MARQUIS, JEAN-MARIE, Rimouski, Canada (Leroux & Marquis, Cons. Engrs.)

MERCIER, GORDON K., JR., Pasco, Wash. (Engr., General Electric Co.)

NEWELL, RICHARD C., Tacoma, Wash. (Designer, Smith & Murray)

NICHOL, FRANK E., Long Beach, Calif. (Secretary, Moffatt & Nichol, Engrs.)

PALANDE, H. A., Madison, Wis. (Stud., Univ. of Wis.)

PELLEGRINI, ALFRED L., East Orange, N. J. (A. Pellegrini & Assocs., Struct. Engrs.)

PRIETO, ATILIO GARCIA, San Salvador, El Salvador (Prieto y Perla, Ingenieros, Cons. Engrs.)

PROMINSKI, JOHN M., Ft. Lauderdale, Fla. (Salesman, Grad. Engr., R. H. Wright & Son)

QUIROGA AVILES, JUAN, Lima, Peru (C. E., Sub-Director de Fomento y O. P., Ministerio de Fomento y O. P., Catedratico Universidad de Ingenieria)

REDFERN, JOHN D., Ottawa, Canada (Tech. Engr., Sales Dept., C. E., Canada Cement Co., Ltd.)

SHULDES, ROBERT W., Chicago, Ill. (Engr., PCA)

SIPE, CHARLES A., Kingsport, Tenn. (Constr. Supt., Bays Mountain Constr. Co.)

SLAGLE, KNOX A., Duncan, Okla. (Dev. Engr., Halliburton Oil Well Cementing Co.)

SWAMINATHAN, S. S., Jabalpur, Madhya Pradesh, India (Supt. Engr., Civil, M. P. Electricity Board)

TILSEN, BENJAMIN L., St. Paul, Minn. (Pres., Litestone Corp.)

VASATKA, RICHARD J., Minneapolis, Minn. (Chf. Struct Engr., Magney, Tsuler & Setter)

WENTINK, E. C., Rotterdam, Holland (Vice-Dir., Pub. Wks., Municipality of Rotterdam)

WERKEMA, J. E., Midland, Mich. (Industrial Research Analyst, Dow Chemical Co.)

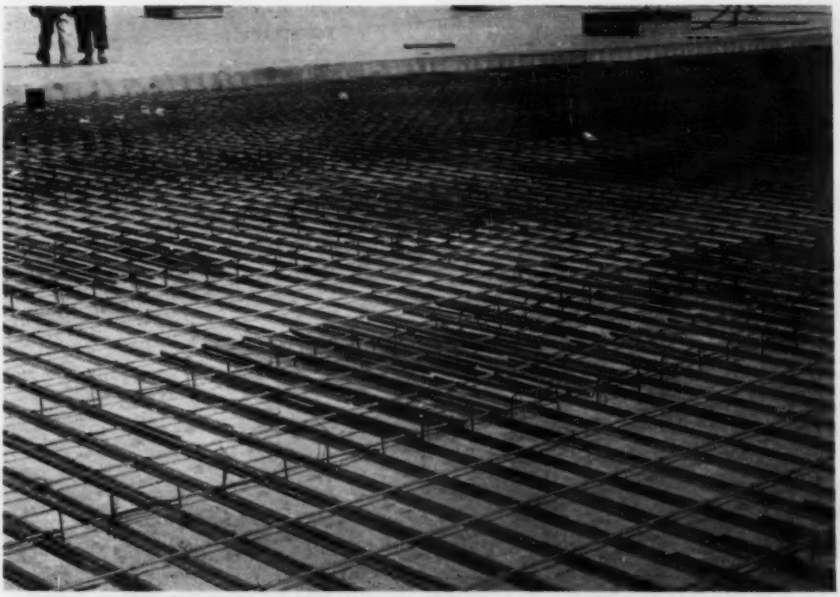
WHITE, ARTHUR FREDERICK, Fredericton, Canada (Stud. Univ. of New Brunswick)

ZWEIG, ALFRED, Detroit, Mich. (Sr. Struct. Engr., Albert Kahn Associated, Arch. & Engr.)

Corporation

CAMPANELLA & CARDI READY MIXED CONCRETE CO., Hillsgrove, R. I. (Americo S. Cardi, Pres.)

FOUNDATION OF CANADA ENGRG. CORP., LTD., Toronto, Canada (H. W. H. Casperd, Supv., Field Engrg.)



LACLEDE PREFABRICATED SLAB REINFORCEMENT SAVES 100,000 TIES IN NEW PLANT CONSTRUCTION

Laclede multi-rib round reinforcing bars shop welded into special prefabricated units saved hours of costly time in the construction of floor slabs for Chrysler Corporation's new St. Louis Assembly Plant.

Eighty-seven thousand of these top and bottom steel reinforcing units, each consisting of two bars up to 15′ long welded to supporting frames, were used in the construction of 485,000 square feet of flooring.

Fabricated to extremely accurate dimensions, units were easily handled and dropped into place on the metal deck. Approximately 100,000 ties were saved by the use of these special Laclede-designed units.

CHRYSLER CORPORATION ST. LOUIS ASSEMBLY PLANT
St. Louis County, Mo.
***General Contractor:* H. D. Tousley Co., Inc., Indianapolis**
***Architect:* Albert Kahn,**
Associated Architects and Engineers of Detroit

LACLEDE

LACLEDE STEEL COMPANY

ST. LOUIS, MISSOURI • Producers of Steel for Industry and Construction

LEHRSTUHL FUR MASSIVBAU DER TECHNISCHEN HOCHSCHULE, Hannover, Germany, (Prof. Dr. Ing. W. Zerna)
SHAW & SONS, LTD., A. N., Toronto, Canada (L. H. Fitzwilliam, Chf. Engr.)

Junior

BAKHAIA, MATTI T., Baghdad, Iraq (Struct. Engr., Public Bldgs. Dept.)
BERTKEN, THOMAS GALEN, San Francisco, Calif. (Asst. Bridge Engr., Calif. Dept. of Pub. Wks., Div. of San Francisco Bay Toll Crossing)
BURTON, JOHN C., East Aurora, N. Y. (Transmission & Distribution Engrg., Niagara-Mohawk Power Corp.)
BEJARANO, JOSE ESQUENAZI, Vedado, Cuba (C. E.)
FINN, RICHARD WALTER, Indianapolis, Ind. (Sales Engr., Hydraulic Press Brick Co.)
FLUHR, WALLACE E., Urbana, Ill. (Grad. Stud. in Civil Engrg., U. S. Air Force, Univ. of Ill.)
KELLER, M. DEAN, New Orleans, La. (C. E. Bedell & Nelson, Engrs.)
LARSON, STEWART P., Walnut Creek, Calif. (Jr. C. E., Calif. Dept. of Pub. Wks., Div. of San Francisco Bay Toll Crossings)
LEOTTA, ANTHONY A., Arlington, Va. (Design & Supv. of Constr., Potomac Electric Power Co.)
MARRA, SAMUEL A., Ciudad Trujillo, Rep. Dom. (Arch., Engr., Constr. & Designing)
MENDEZ-AROCHA, DR. RAFAEL, Caracas, Venezuela (Field Engr., CAMIFA, S. A.)
PENA VICUNA, MANUEL ANGEL, Cabimas, Venezuela (C. E., Creole Petroleum Corp.)
PIERSON, REED J., JR., Langley AFB, Va. (1st Lt. O.I.C. Proj. Preparation Section)
POISSON, ANDRE, Montreal, Canada (Jr. Bridge Engr., Quemont Constr., Inc.)
PEREE DE VARGAS, Aldo Ruben, La Plata, Argentina (C. E.)
VELASCO-GUERRA, JOSE RAMON, Caracas, Venezuela (Inspection, Ingenieria de Suelos)

Student

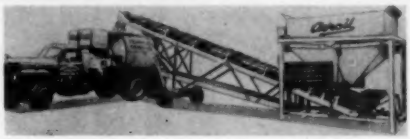
AGGARWALA, OM P., Ft. Wayne, Ind. (Indiana Tech. College)
AREVALO, ARMANDO EFRAIN, Guatemala, Guatemala (Univ. de San Carlos)
BYRNE, J. G., Dublin, Ireland (Trinity College)
CAHOON, THOMAS H., Champaign, Ill. (Univ. of Ill.)
COZZA, JOHN M., Chicago, Ill. (Univ. of Ill.)
FOSTER, JOHN V., Urbana, Ill. (Univ. of Ill.)
LINDAHL, RAYMOND E., Urbana, Ill. (Univ. of Ill.)
MUSLEH, FOUAD E., W. Lafayette, Ind. (Purdue Univ.)
NG, MICHAEL B. K., North Coburg, Australia
NOURACHI, HASSAN, New Orleans, La.
OLDEN, ROBERT, Champaign, Ill. (Univ. of Ill.)
PEASE, CHARLES ENNIS, Chicago, Ill. (Ill. Inst. of Tech.)
SAVAGE, EDGAR C., Seattle, Wash. (Univ. of Wash.)
SCHAFER, IRVIN B., Champaign, Ill. (Univ. of Ill.)
SKUJA, JOHN J., Norman, Okla. (Univ. of Okla.)
VELIE, JAY E., Columbia, Mo. (Univ. of Mo.)

Tools, Materials, Services

Under this heading note is made of producer literature and products of presumed technical interest to ACI users of tools, equipment, materials, accessories, and special services.

Portable batch plant

Aeroil Products Co. announces a portable concrete batching plant available in 3½ and 6 cu yd sizes. Mounted on 4 wheels for easy towing, the total weight



is 6500 lb. It can be powered by either a gas engine or electric motor.

The conveyor is 35 ft long and has a high speed 24-in. belt. Photograph shows the unit in the working position with the rear wheels removed.—Aeroil Products Co. Inc., 69 Wesley St., S. Hackensack, N. J.

Make your own test of waterproofing paste

Integral Waterproofing Paste is now being marketed by Forrer's, who claim this product plasticizes and entrains air as well as waterproofs concrete, cast stone, all types of masonry units, split rock, stucco and mortar. For a limited time a free sample is offered so that the user can make his own tests. Upon request manufacturer will send a 5-gal pail (approximately 40 lb); those ordering free sample are asked to pay the freight and limit their request to one pail. About ½ to 1 lb of paste per bag of cement is advised, depending on the mix.—Forrer's Products for Masonry, 2225 N. Humboldt Ave., Milwaukee 12, Wis.

Fibre forms for columns

Deslauriers Column Mould Co. has added a low cost round fibre form to its line of steel forms and capitals for round concrete columns.

Called Econ-O-Mold it was designed to reduce time and labor on jobs requiring "single use" or a limited

MAGNETITE AND ILMENITE
HIGH-DENSITY CONCRETE AGGREGATES
FOR
NUCLEAR SHIELDING
NUCLEAR SHIELDING SUPPLIES & SERVICE, INC.
175 Main St. White Plains, N.Y. ROckwell 1-1214

TIDEWATER OIL COMPANY HOME OFFICE
4251 Wilshire Blvd., Los Angeles, California

Owner: Tide Water Realty Company
Architect: Claud Beelman and Associates
Engineer: Brandow and Johnston
Contractor: C. L. Peck Construction and Realty Company
Laboratory: R. G. Osborne Laboratories, Inc.
Concrete: San Gabriel Ready Mixt of Inglewood
Structure: Multi-story, conventional, lightweight concrete

HIGHER STRENGTH

at Lower Cost with... MARACON NONPEAK

WATER-REDUCING
ADMIXTURES for CONCRETE

1 IMPROVE CONCRETE QUALITY: —

MARACON® promotes more complete hydration of cement particles and permits a substantial reduction in the unit water content without loss of plasticity or consistency of the mix. Low water content means higher strength.

A. Minimize shrinkage in concrete before and after hardening, due to lower water content and more complete hydration of cement.
B. Decrease permeability.
C. Achieve greater density and higher durability factors.

2 LOWER CONCRETE COSTS: —

A. Maintain slump and workability at low W/C ratios.
B. Attain higher strengths without increasing cement content of a mix.
C. Permit economical redesign of conventional concrete mixes.

MARACON also reduces water requirements in concrete mixes containing pozzolanic materials.

DISTRIBUTORS

West of the Rockies, Hawaii and Alaska
Admixtures, Inc.
965 N. Fair Oaks Ave.
Pasadena, California

East of the Rockies
Truscon Laboratories
Division of
Devoe & Raynolds Co., Inc.
1700 Caniff, Detroit 11, Mich.

(Mississippi only)
Ready-Mix Concrete Company
Meridian, Mississippi

Use the coupon for more information.

MARATHON • A Division of American Can Co.
CHEMICAL SALES DEPT. • MENASHA, WIS.
Send additional information on Maracon to: —
NAME _____
COMPANY _____
ADDRESS _____
J-29

MARATHON
A Division of American Can Company
CHEMICAL SALES DEPARTMENT
MENASHA, WISCONSIN

number of round concrete columns for underpinning, stub columns, quarter, half and obround columns. Lightweight, easy to store on the job, and easy to saw to fit any size column, the mold is said to require fewer men to handle and erect.

Made from heavy-duty impregnated fibre, forms have wax coated exteriors and plastic lined interiors. Standard 18 ft lengths are available in 3 to 48 in. I.D. Special lengths are obtainable on request.—Deslauriers Column Mould Co., Inc., 5036 W. Lake St., Chicago 44, Ill.

Flexible tubing for post-tensioned concrete

Duoflex, a flexible tubing currently being used to encase cable, rod, strand, or wire in prestressed concrete where the post-tensioning method is used, has been patented by Flexico Products, Inc. A reinforcing rib formed in the wall of the tubing is said to afford increased crushing strength and a superior bonding surface when buried in concrete. According to Flexico, these ribs will prevent disengagement of the slidable joints, because, when the tubing is bent, the rib will limit the movement of the slidable joint thereby preventing breaking of the tubing if overbent.

Manufacturers further stress that the tubing is light in weight because of the economical use of steel, making it easy to handle on the job site and reducing transportation costs.—Flexico Products, Inc., Factory St., Metuchen, N. J.

Concrete finisher

Instant Trowel concrete finishers are now available in six different models including both 3 and 4-blade machines in 32 in. and 42 in. trowel diameter sizes. There is also a model equipped with an 18-in. grinding disc and another machine equipped with a 24-in. floating disc.

According to the manufacturer, the Dura-T blade reduces blade replacement costs as much as 50 percent. This is a combination blade for both floating and finishing. It operates independently of the Wisconsin air-cooled engine, and once set, the blades hold the set angle until operator desires to make a change.—Cook Brothers Equipment Co., 3334 San Fernando Road, Los Angeles 65, Calif.

Epoxy paste

Furane Plastics announces the availability of Epocast 546, an epoxy paste, which, according to the manufacturer, is capable of curing firm and hard in underwater locations.

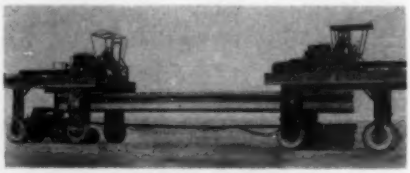
After Epocast 546 has been combined with its hardener (Hardener 9514), it may be trowelled or squeeged into position. Hardening takes place in several hours, overnight under moist conditions, and will develop good adhesion to clay pipes, concrete products, stone, metals, and other miscellaneous products according to the company.—Furane Plastics, Inc., 4516 Brazil St., Los Angeles 30, Calif.

Straddle carrier

Designed and manufactured by Silent Hoist and Crane Co., Brooklyn, N. Y., the Strad-Krane is a mobile straddle carrier. It is self-propelled on pneumatic tires.

The two carriers pictured in use by the American Marietta Co. in Hodgkins, Ill., have a capacity of 25 ton each and travel up to 10 miles per hr, forward or reverse. Smaller and larger capacities are available for specific applications.

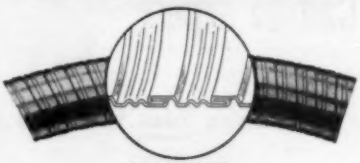
Prime feature of the carrier is that the center of the load is inside the wheel supports. This eliminates the



need for counterweights, stabilizers or jacks, allowing freedom in mobility. Load to be carried is suspended from a hook under the frame of the unit. The hook is controlled by a trolley bridge hoist located on the top structure. The hook can travel from one end of the machine to the other transversely and up and down, duplicating the action of a shop overhead crane.

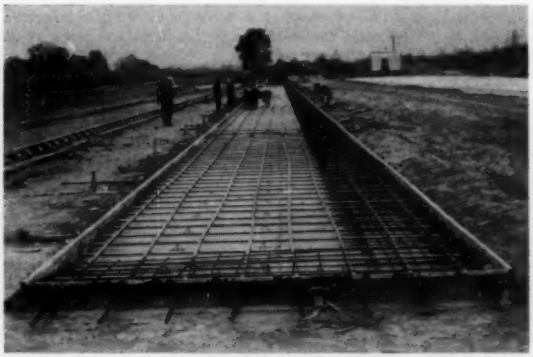
Carrier comes equipped with power steering, power brakes. A 450 cu in. 6 cylinder power plant, and automatic transmission. The hoisting element for the main hook lines and for the power trolley is through a hydraulic transmission.—Silent Hoist and Crane Co., Dept. 205, 841 63rd St., Brooklyn 20, N. Y.

Lower Cost
Flexible
POST TENSION CASING



U-100WP
(Wide Profile)
ECONOFLEX
Ask for Bulletin U-100WP

QUALITY...*All Metal*
Flexible Hose Products
Universal
METAL HOSE CO.
2101 S. Kedzie Ave., Chicago 23, Ill.



LARGEST PRESTRESSED PAVEMENT built in the United States was recently completed near Sharonville, Ohio. The pavement, 500 ft long and 51 ft wide, is part of an experimental heavy-load test track for the Ohio River Division Laboratories of the U.S. Army Corps of Engineers. The 9-in. pavement is designed to carry twin-tandem airplane landing gear weight of 325,000 lb. The 51-ft width was paved in four lanes. Concrete was placed on a layer of waterproof paper over a ½-in. sand cushion, specified to reduce sliding friction between slab and subgrade.

Longitudinal prestressing was accomplished with high strength steel bars enclosed in flexible metal conduits, which were placed in position before concreting and jacked to prescribed tension. Transverse prestressing was done after all four lanes had been paved. Steel bars were inserted through rigid metal tubes placed in position before concreting. Grout was pumped into the conduits after jacking.

Construction was by W. L. Harper Co., Cincinnati. Stress-Steel Corp., Wilkes-Barre, Pa., was subcontractor for furnishing and jacking the prestressing bars.

POUR CONCRETE ALL WINTER?

Call an expert your Ready-mix Supplier

. . . have **him** tell you why **SPECIAL WINTERIZED** Concrete

containing **SOLVAY CALCIUM CHLORIDE*** offers you these **6** money-saving advantages . . .

• Added safety • Quicker setting • High early strength
• Savings in protection time • Less delay between operations • Full ultimate strength

*SOLVAY® CALCIUM CHLORIDE speeds, but does not change, the basic action of portland cement. This use of calcium chloride is approved by Portland Cement Association, American Concrete Institute, Calcium Chloride Institute, leading highway departments.

Write for SOLVAY'S newly-revised 38-page booklet, "The Effects of Calcium Chloride on Portland Cement."

Allied Chemical

SOLVAY PROCESS DIVISION
61 Broadway, New York 6, N. Y.

SOLVAY branch offices and dealers are located in major centers from coast to coast.

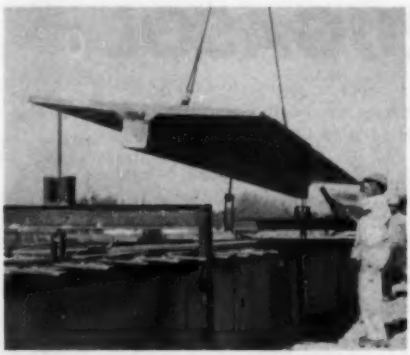
Precast lightweight cellular concrete building panels and block

Siporex Northeastern Inc. has been established with headquarters in Syracuse, N. Y., for the manufacture of precast lightweight cellular concrete building panels and block. "Siporex" is manufactured from pulverized sand, portland cement, aluminum powder, and water. These ingredients are precisely measured and carefully mixed, and are poured into large molds. Here, a chemical reaction takes place which causes the mixture to rise like dough, forming tiny bubbles throughout the material. Resulting "cakes" are cut into the shapes and sizes required for building block, wall panels, or roof and floor slabs. They are then placed in autoclaves and cured under high pressure steam.—Siporex Northeastern Inc., P. O. Box 29, Syracuse, N. Y.

Prestressed T-sections now available

Span loading tables, specifications, and franchise to use the Lin T-system are now available to manufacturers of prestressed concrete products.

The load tables include depths of members from 12 to 36 in. with spans up to 120 in. for building members



and to 60 ft for bridge members. Both 6 and 8 ft widths are tabulated and tables are available for both lightweight and conventional concrete.

The system allows a producer to cast from one set of forms all practical sizes of members up to the maximum size which can be generally transported. The system meets the concrete coverage requirement for a 2-hr fire rating as specified in Underwriters Laboratory Fire Test Report R4123-1 dated May 12, 1958.—T. Y. Lin and Associates, 14656 Oxnard St., Van Nuys, Calif.

Dry bulk transport features twin-screw unloading

Twin-screw unloading steel trailer designed to haul all types of heavier dry bulk materials such as cement and fly ash has been announced by Butler Mfg. Co.

Company states that the design of the transport permits bigger dry bulk payloads with heavy-duty construction for longer trailer life; also that the "clean bore" interior of the trailer's 60 deg slope side walls assure positive flow to the twin-screws and permit fast, continuous unloading without material hang-up or bridging.

Available in 640, 740, and 840 cu ft capacities. Custom units that meet individual customer requirements and hauling capacities will also be built.—Butler Mfg. Co., 7400 E. 13th St., Kansas City 26, Mo.

LOOKING AHEAD

Feb. 23-26, 1959—American Concrete Institute, 55th Annual Convention, Statler Hilton Hotel, Los Angeles, Calif.

Apr. 5-9, 1959—1959 Nuclear Congress: an assembly of the 7th Hot Laboratories and Equipment Conference; 5th Nuclear Engineering and Science Conference; 7th Atomic Energy Management Conference; and Atomfair. Engineers Joint Council, Public Auditorium, Cleveland, Ohio

Apr. 6-8, 1959—8th Annual Meeting, Building Research Institute, Penn-Sheraton Hotel, Pittsburgh, Pa.

May 13-15, 1959—"Deutsche Betontog 1959," German Concrete Association, Congress Hall of the German Museum, Munich, Germany

May 18-19, 1959—39th Annual Meeting, The Society of American Military Engineers, Washington, D. C.

A Simple Way to
EXPOSE CONCRETE AGGREGATE
... Use RUGASOL
You will find that exposing concrete aggregate with Sika Rugasol is simple because it eliminates the need for costly chipping, hacking or sandblasting. There are two types of Rugasol:
RUGASOL F . . . is painted directly on formwork. When forms are stripped (in 2 to 5 days), the retarded mortar is removed with a jet of water or stiff brush.
RUGASOL C . . . is applied on the surface of freshly placed concrete. On the following day, the retarded surface mortar is removed with a jet of water or stiff brush.
For complete information on Rugasol, call or write for Bulletin RG-58.

Sika

SIKA CHEMICAL CORPORATION

PASSAIC • NEW JERSEY

DISTRICT OFFICES: ATLANTA • BOSTON • CHICAGO • DALLAS • DETROIT • PHILADELPHIA • PITTSBURGH • NEW ORLEANS
SALT LAKE CITY • WASHINGTON, D. C. — DEALERS IN PRINCIPAL CITIES — AFFILIATES AROUND THE WORLD

Literature Available

Pertinent details on the latest equipment and products on the market are available in recently released literature. Exact titles of the booklets and catalogs are indicated in capital letters. They may be requested direcly from the manufacturers listed below.

TWAITS-WITTENBERG CO.—A 24-page institutional brochure has been recently released by Twaits-Wittenberg Co., Los Angeles constructors and engineers, setting forth the organization's construction accomplishments during the past 40 years, its services, and construction approach.

One section deals with methods and materials, and the wide use made of lift-slab and tilt-up construction.

Describes Twaits-Wittenberg's various operations, including job management and services such as joint ventures, site selection, and financing.—Twaits-Wittenberg Co., 507 South Bixel St., Los Angeles 17, Calif.

CALCIUM CHLORIDE IN CONCRETE—40-page technical manual, contains data on major effects of calcium chloride relating to its advantages on initial and final set, early strength, ultimate strength, cold weather protection, and high-early-strength cement and air-entrained concrete.

Photographs show use of calcium chloride in concrete projects and the charts contain laboratory data from numerous nationally recognized technical organizations. Single copies available.—Calcium Chloride Institute, 909 Ring Building, Washington 6, D. C.

FULLER FACT FILE ER-3241-1—Bulletin discusses all phases of cement manufacturing at a new 200,000-ton cement plant located in England.

The 12-page bulletin gives information on sizes and types of equipment used at the plant from the initial quarrying of raw materials to delivery of the finished product in bulk or bags.

A special section is devoted to a discussion of the operation of two 560-ton raw meal blending and storage silos equipped with the Fuller Airmerge quadrant blending system. Other sections cover kiln operation and clinker cooling.—Fuller Co., Catasauqua, Pa.

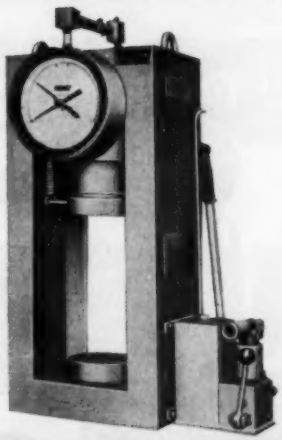
HOW TO INSTALL SPANG HEADERDUCT—Spang Headerduct is an underfloor wire distribution system designed for coordination with cellular floor construction. In this system, wires are carried in headers which run at right angles to the floor cells. The ducts feed wiring into the cells at regular intervals, thereby providing underfloor wiring to all parts of the area. Step-by-step, illustrated instructions are given for installing this underfloor wire distribution system for power, telephone, and intercommunication systems in this 24-page booklet.—Spang-Chalfant Division of the National Supply Co., Pittsburgh, Pa.

BIRD TERMIBAR—Bulletin describes product which combines a vapor barrier with an insecticide which kills termites. The product is designed primarily to go under concrete slabs in new home construction. The barrier consists of an impervious plastic film plus a layer of felt impregnated with Dieldrin insecticide developed by Shell Chemical Corp. Company claims the presence of this insecticide not only kills termites, but renders the soil immediately beneath it toxic to them. Bulletin explains how product works and shows typical installation.—Bird and Son, Inc., East Walpole, Mass.

CONCRETE PAVING SPREADER (Bulletin No. 2485R)—Three-color product bulletin contains 16 pages of on-the-job pictures, spreader operation diagrams and a job-proved paving method; highlights the spreader's automatic transverse blade and vibratory paving attachment.—Blaw-Knox Co., Sales Promotion Dept., Mattoon, Ill.

PEOPLE AND MOVEMENT—Title of a 17-min color film discussing the changes in America's population and how these changes are affecting land use and movement in urban, suburban, and rural areas of the

MODEL FT 20
JOBSITE
CONCRETE TESTER



FOR: CYLINDERS, CORES, BLOCKS, BEAMS, CUBES, BRICK AND DRAIN TILE
FORNEY'S INC.
TESTER DIVISION
BOX 310, NEW CASTLE, PA., U.S.A.

nation. The sound film is aimed at increasing the public's understanding of planning behind highways now being built across the nation as part of the national system of interstate and defense highways.

Film shows expressways, redevelopment models, slum clearance projects, and rural industrial developments from all over the country. It is intended for showing to civic groups, schools, service organizations, and other interested audiences and is available through Portland Cement Association district offices.—Portland Cement Association, 33 West Grand Ave., Chicago 10, Ill.

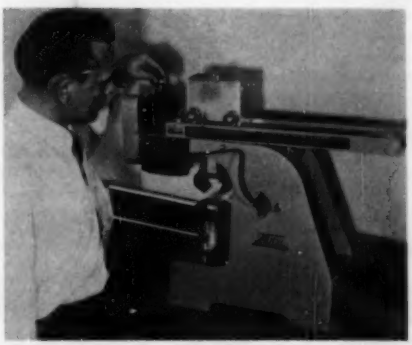
1958 WILLIAMS FORM ENGINEERING CATALOG (No. 1958)—A 67-page indexed catalog showing the latest engineered products and proved methods of concrete forming devices for both light and heavy construction. Profusely illustrated.—Williams Form Engineering Corp., 1501 Madison Ave., S. E., Grand Rapids, Mich.

TAPPING PRESTRESSED CONCRETE PRESSURE PIPE—Pocket-size manual on how to tap concrete pressure pipe. Includes a series of on-the-job photos and instructions which give step-by-step procedure for tapping prestressed concrete steel-cylinder pipe under pressure.—Price Brothers Co., 1932 E. Monument Ave., Dayton 1, Ohio.

Portable briquet tester

Soiltest, Inc. recently introduced a compact cement briquet tester, Model CT-700A, designed to meet need for portability.

The tester applies loads at a constant rate to a specimen of cement mortar held in the jaws of the tester. The failure point of the specimen, in terms of pounds



of load applied, gives the tensile strength of cement mortar according to the ASTM C 190.—Soiltest, Inc., 4711 W. North Ave., Chicago 39, Ill.

RELY ON-

WORLD'S MOST WIDELY USED AIR METERS

First in Design—First in Sales
Guaranteed Accuracy for Testing Air Entrained Concrete
Fast • Simple to Operate

PRESS-UR-METER

Sample remains intact. Small amount of water used in test permits using same sample for slump and compression tests. Universal acceptance — America, Europe and Asia. Specific gravity and moisture determinations quickly made using chart.

ROLL-A-METER

Simplified device for testing light weight concrete. Precision instrument made of solid bronze. Requires no computation — no special training. Reliable — durable.

ASTM Designation: C173-55T
Write or wire exclusive sales agents
CHARLES R. WATTS CO.
4121 6th Ave., N.W.—Seattle 7, Wash.

Membership in the American Concrete Institute

To facilitate prospective members in joining the Institute, membership application forms are provided. Present Members may aid by bringing these forms to the attention of those who may profit from membership advantages. The grades of membership are described overleaf.

All who have an interest in concrete are eligible for membership.

Members have at hand in Institute publications the most complete fund of knowledge on concrete. The ACI JOURNAL provides them with the latest information and ACI special publications provide them with the complete picture of specific problems. Through conventions, and regional and area meetings they are afforded the opportunity of meeting those whose experiences provide the new information, and of exchanging ideas with them.

Opportunity for service is present in technical committee activity, in contributions, or only comments, to the ACI JOURNAL, or in reviewing technical publications for material of interest to the membership.

ACI's world-wide membership is growing in extent and participation—traveling a common road toward better, more economical and durable concrete structures. ACI provides a common ground in the search for and use of new "working tools" in concrete design, manufacture, and erection—and its interpretation.

(cut here)

Board of Direction, American Concrete Institute
P. O. Box 4754, Redford Station
Detroit 19, Michigan

Date_____

Individual Members (U. S. and Possessions, Canada, Mexico, Central America, and West Indies)	$15.00
Individual Members (All other foreign countries)	12.00
Corporation Members	50.00
Contributing Members	100.00
Junior Members—nonvoting (under 28)	7.50
Student Members—nonvoting (under 28)	5.00

(Subject to stipulations of Bylaws—Article I on reverse side. Bylaws on request.)

Of the annual dues, $12.00 is for the JOURNAL of the American Concrete Institute (except that dues for Junior and Student Members apply in full for the JOURNAL).

The undersigned hereby applies for_____membership
(Individual, Corporation, Contributing, Junior, Student)

in the American Concrete Institute. Proposed by_____

For Corporation Membership, ACI representative will be_____

_____ _____
(Date of graduation if Student) (Name, if Corporation)

Signature_____

For our records, please complete both sides of application.

EXCERPTS FROM BYLAWS: ARTICLE I—MEMBERS

Section 1. This Institute shall consist of Honorary Members, Corporation Members, Contributing Members, Members, Junior Members and Student Members.

Sec. 3. A Member shall be a person.

A Corporation Member shall be a firm, corporation, society, agency of government, or other organization.

A Contributing Member shall be a person, firm, corporation, society, agency or government, or other organization electing to give greater support to Institute activities through the payment of larger dues. Any Contributing or Corporation Member, other than a person, may name a personal representative who shall enjoy all membership rights and privileges.

A Junior Member shall be a person less than 28 years of age.

A Student Member shall be a person less than 28 years of age and a registered student at a technical or engineering school.

Sec. 4. All classes of Members, except Honorary Members and Student Members, shall be sponsored by at least one Member of the Institute. An Honorary Member shall be elected by unanimous vote of the Board of Direction. A Student Member shall be sponsored either by a Member of the Institute or by a member of his school's faculty, who need not be a Member of the Institute.

Sec. 5. All Members in any classification shall have all rights and privileges of membership as determined by the Board of Direction except that a Junior or Student Member shall neither vote nor hold office. The status of a Student Member shall change automatically to that of Junior Member or Member, depending on age, on the first anniversay of his membership succeeding the date on which he ceases to be a registered student. The status of a Junior Member shall be changed to that of Member on the first anniversary of his membership after he becomes 28 years of age.

Sec. 6. Applications for and resignations from membership and requests for change of representatives of Corporation or Contributing Members shall be presented in writing to the Secretary-Treasurer. Resignations may be accepted only from Members whose dues are not more than 60 days in arrears, except by special action of the Board of Direction.

(cut here)

Name _____
Please Print

Date of Birth _____
Month Day Year

Title or Position _____

Name of Firm or Organization _____

☐ **Business Address** _____

☐ **Resident Address** _____
(Please check address to which you wish mail and publications sent)

Nature of Firm's Business _____

The ACI Membership Directory will be sent—as available—only on request.
Check here if you wish to receive the latest edition. ☐

Longitudinal float road finishing machine

A longitudinal float road finishing machine is being offered as part of the line of Rex road building equip-

ment. Basic frame members are made of tubular construction for over-all strength with flanged frame corner connections for easy disassembly for transportation according to the manufacturer. The float includes grouped controls and safety catwalks.

The actual finishing operation of the machine is accomplished by a carriage which travels transversely between the tubular frames on a set of single crowned rails. Crown adjustment is done through a single point handwheel control at the front and rear of the machine for each rail. An independent power unit on the floating carriage allows independent control of carriage speed and traction speed. Automatic mechanical trip lever on the unit reverses carriage direction at each end of the cycle.

The machine is supplied in two basic width adjustments: 10 to 15 ft and 20 to 25 ft.—Chain Belt Co., 4701 W. Greenfield Ave., Milwaukee 14, Wis.

Marcon named plant manager of Alpha Catskill plant

Frank B. Marcon has been promoted to plant manager of the Catskill, N. Y., plant of Alpha Portland Cement Co. He joined Alpha in 1954 as plant engineer. Mr. Marcon replaces J. A. Anderson, who recently resigned.

Burres named district engineer of PCA Los Angeles office

The appointment of Warren G. Burres to the position of district engineer of the Portland Cement ssociation's Los Angeles office was recently announced.

Mr. Burres, formerly PCA personnel training manager, succeeds John M. McNerney, who was recently appointed manager of the association's western regional office.

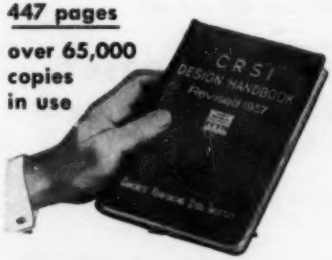
Walter E. Kunze, Jr. will succeed Mr. Burres as manager of personnel training.

The QUICKEST way to get REINFORCED CONCRETE DESIGNS

Revised 1957 . . . Based on Latest A. C. I. Building Code

447 pages

over 65,000 copies in use



$6.00 POSTPAID

10 Day Money Back Guarantee
NO C.O.D. ORDERS

Bring your reference library up to date. Replace your earlier (1952) edition of the CRSI Design Handbook. Completely revised in 1957, this valuable tool will provide you more Reinforced Concrete Designs, all worked out to the latest A.C.I. Building Code. Here is a technical publication of immeasurable value, which the Concrete Reinforcing Steel Institute is making available to architects and engineers for only $6.00 a copy. Send check or money order for your copy, today.

Prepared by the Committee on Engineering Practice

CONCRETE REINFORCING STEEL INSTITUTE

38 S. Dearborn St. (Div. J), Chicago 3, Illinois

ALPHABETICAL LIST OF ADVERTISERS

(Page Numbers refer to News Letter)

American-Marietta Company, Concrete Products Division 6

Colorado Fuel and Iron Corporation, Clinton Division 18

Concrete Reinforcing Steel Institute 31

Forney's Inc., Tester Division 27

Jackson & Moreland, Inc. 19

Laclede Steel Company 20

Marathon, Division of American Can Co. 22

Master Builders Company, The, Division of American-Marietta Co. 16

Nuclear Shielding Supplies & Service, Inc. 21

Rail Steel Bar Association 10

Sika Chemical Corporation 26

Solvay Process Division, Allied Chemical 24

Sonoco Products Company 9

Universal Metal Hose Company 23

Water Seals, Inc. 17

Charles R. Watts Co. 28

The Institute assumes no responsibility for the claims of advertisers. The advertiser is made responsible in the belief that his place in the field will be determined by the public's ultimate measure of his exercise of that responsibility.

NOTICE — Change of Address — NOTICE

To avert any delay in receiving my ACI JOURNAL, I wish to give notice of a change in my mailing address. (PLEASE PRINT)

New Address:

NAME_____

STREET & NO._____

CITY_____ ZONE____ STATE_____

Old Address:

STREET & NO._____

CITY_____ ZONE____ STATE_____

155 Reasons Why...

What is the purpose of air entrainment in concrete?

How can durable aggregates be assured?

How do the requirements of placing affect the proportions of aggregates and cements?

. . . . The ACI CONCRETE PRIMER should be your guide to better concrete. The PRIMER develops in simple terms the principles governing concrete mixtures and presents a handy reference text for those who apply these principles to the production of permanent structures in concrete. Expanded to 72 pages—155 answers—the new pocket-size edition of the CONCRETE PRIMER brings developments of the past three decades into the question-and-answer format of this long-popular handbook.

$0.50 TO ACI MEMBERS NONMEMBERS $1.00

American Concrete Institute, P.O. Box 4754, Redford Station, Detroit 19, Michigan

Please send_____copies of the 1958 edition of the ACI Concrete Primer.
($0.50 for ACI members, $1.00 for nonmembers)

Check (or money order) enclosed for_____amount

Name.....

Address.....

City.....Zone.....State.....

The 55TH Annual

ACI

Convention

8—Sessions—8

- Standards and Bylaws
- Construction
- Special Problems
- Design and Analysis
- Concreting Materials
- Design Research
- Products and Precast Elements
- Research Session

Plan now to attend these "fact-filled" sessions. Assure yourself of the latest and most up-to-date information available in concrete and concrete construction. Make **your** reservations early.

FEB. 23-26, 1959

STATLER HILTON HOTEL, LOS ANGELES